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Van Winkle, Pieter Kingsland.

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Pieter Kingsland Van Winkle

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

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by

Pieter Kingsland Van Winkle

Thesis Advisor: D. Whipple

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Pieter Kingsland Van Winkle
Lieutenant Commander, United States Navy
B.A., University of Notre Dame, 1964

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ABSTRACT

A preliminary model for manpower and budget resource allocation in a Navy Regional Medical Center is formulated. Oakland Naval Hospital is used to illustrate the concept. A functional budget structure is proposed for management use in resource allocation decisions. Submodels of important supporting elements in the functional structure are developed. The problem of suitable definitions for patient category inputs is addressed. The model is suitable for use in analysis of many different types of health facilities with modification as discussed in the paper.

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I. GENERAL INTRODUCTION

Efficient allocation and utilization of health care resources is of prime concern at the present due to critical shortages of qualified medical and para-medical personnel. Adding to the problems generated by these shortages is the demand on health care administrators to adapt to and absorb the product of technological advances in equipment, medical practices and administrative technique. These problems are compounded when large scale health systems are controlled at a central management point such as is the case in military health care and may become the case if national control of all health care delivery systems is ever adopted. Until the past few years the techniques and methodology of systems analysis have not, in general, been directed towards health care administration and delivery because of the difficulties inherent in any attempt to analyze so complex a system at a level sufficient to produce useful results. With the advent of larger computers and more sophisticated analytic tools, and spurred by the rising costs of health care, analysts have begun to study various aspects of the delivery system.

The primary obstacle in the analysis of any system is the definition of an acceptable objective function by which to measure and compare the output of its various components. No widely recognized measure of effectiveness has been developed to date in the health care field. There is currently underway at the U.S. Naval Postgraduate School a

research project with the purpose of developing and testing such measures of effectiveness to be used for resource allocation at the central decision level of large integrated delivery systems. To conduct the evaluations a working model of a health care delivery system was needed. It seemed desirable at the same time to use a model with sufficient flexibility to suit many analytic purposes. Of particular interest was the analysis and evaluation of the effeciency of the recently created Navy Regional Medical Center (NRMC), Oakland, a consolidation of several San Francisco Bay Area Navy medical facilities.

A review of the current literature on hospital and health care system modeling was conducted. None of the models reviewed were suitable for direct use either in the project or as a model of the NRMC, principally because military health care differs from its civilian counterpart in that patients are not charged for treatment and thus cost versus revenue cannot be used as a decision variable by management. While some of the techniques employed were applicable, none of the models dealing with strictly civilian operations were suitable for use. Models that are developed for specific objective functions often are not suitable with other objective functions because the simplifying assumptions allowed in one circumstance may not be justifiable under another.

Concurrent with the problem of defining an objective function in health care is the problem of aggregating

patients into homogeneous mutually exclusive groups for use as inputs or outputs of particular models. Some of the analyses reviewed addressed this problem and proposed various schemes for grouping the patients. Their models then were built around the aggregation scheme. There are two objections to these approaches for the present purpose. First, it seems apriori that flexibility is lost when a fixed aggregation scheme is adopted prior to modeling. With different objective functions it might be desired to use different aggregations. The second objection is that, if the model is to be used by health care administrators to assist in resource allocation, then the most flexible patient designation system is needed so that the decision-maker can use his own expertise in aggregating the patient classes. For this reason patient classes should be defined in terms of currently accepted divisions until better ones are accepted by the health care profession.

Decisions on the effective utilization and allocation of resources should be based on marginal cost and benefits rather than on average figures. Derivation of these marginal quantities without adequate computer resources is difficult. In addition, it is easy for the untrained analyst to confuse the two types of calculations since average figures have been the traditional ones used in managerial analyses. Models based on average figures were not in general suitable for this study. Two models, the first by H. H. Baligh and D. J. Laughhunn [Ref. 1], the second by D. Schneider, S. R. Roberts

and K. Kilpatrick [Ref. 3], while rejected for direct incorporation into the study, provided considerable insight into modeling the NRMC. In particular their adaptations of linear programming techniques to hospital modeling are used throughout the present effort.

As a result of the literature survey it was decided to develop a model specifically of the Navy Regional Medical Center which would be flexible enough to be used for any health system in the public sector with only minor modifications. Recalling the potential ultimate use of this model, the remainder of this paper will explain the development and use of the model paying particular attention to descriptions of variables and their measurement; and analysis of patient inputs. This paper is written so as to be usable by persons untrained in systems analysis, therefore an attempt has been made to keep explanations simple. Interspersed throughout the main body and appendices are explanations of terms and ideas which for another audience could go unmentioned.

II. PREFACE TO NRMC MODEL

A. BACKGROUND

Prior to 1973 medical support of the Navy community in the San Francisco Bay Area was provided by Oakland Naval Hospital and ten dispensaries located at various naval facilities. Informal cooperation existed among these units but each was organized, funded and managed independently. Beginning in January 1973 these eleven units were combined into the Navy Regional Medical Center, Oakland, under the general control of the Commanding Officer, Oakland Naval Hospital. In theory the NRMC is one system under complete control of a central system management. However, the transition is not yet complete and vestiges of independence continue to exist. A model capable of analysing the costs and benefits of different management policies would be useful during this transition period.

The current organization of the NRMC is similar to that of Oakland Hospital which is organized on the traditional basis of function. Two major divisions are defined: medical and administrative. The medical division is subdivided into services by medical specialty headed by the senior officer in that service. Heads of service, acting semi-independently under the supervision of the hospital's executive officer (a physician), are responsible for the provision of inpatient and outpatient services. There exists an outpatient service with the potential to exercise coordinating control over

outpatient operations. Its present function is mainly administrative support to outpatient operations and operation of the general practice (screening) clinic. Budget allocations are difficult to categorize simply due to the mixed source of funds provided by different Navy bureaus. In general, budget control is exercised on the same lines as the administrative structure. There exists a nominal program budget structure for operating funds, however its purpose is to account for expenses on various programs, not to provide budget control to program managers on functional lines. There is no existing cost accounting system to readily calculate costs across administrative divisions in order to, for example, compute the total cost of operating a specific clinic taking into account supporting services. Workload reporting, on the other hand, is at least divided into the two basic divisions of inpatient and outpatient services.

B. CONSIDERATIONS IN MODELING THE NRMC

Models in general are of two types: explanatory or predictive. Explanatory models treat the system modeled in great detail so that the interactions between areas can be studied. As a result of this detailed analysis a simplified model can be developed which incorporates the essential features of the system and, despite its simpler treatment, approximates the reality of overall operations. The simplified model facilitates studying the effects of hypothesized changes in the input parameters of the model and thus becomes an important tool for management, enabling it to examine the

possible effects of policy changes dealing with resource allocation. Since the interactions between elements of the NRMC are not well understood, the present effort is directed toward developing a detailed model for the initial analysis.

Time is an important variable in many systems and can be modeled in two ways. Static models treat time as fixed by using cumulative inputs to generate cumulative outputs for a specified period, for example, a month or year. Such models are useful for examining the gross effects on components of the system by total operations, pointing out areas whose magnitude of activity is sufficiently small to be treated as fixed and thus external to the model. Dynamic models treat time as a variable and model system activity in shorter periods, and may use the output of one period as one of the inputs to the next. These models are useful when the input varies with time as is the case with the patient mix arriving at a medical care system. To some extent the construction of a model depends on the time period to be used. A model built for a specific time period can be used for time periods greater than that with little modification but computational resources may be wasted. Shorter time periods may require variables that were not included in the original analysis. While in many areas of the NRMC a study of the hourly work-load is needed, the current model is designed with a daily period in mind. Because both static and dynamic models are needed at the current stage of analysis the model must be structured so as to be used either way with minimum change.

The form and content of a model depend on the purpose for which it will be used. In general an analytic model for managerial studies consists of an objective function defined in terms of variables which quantify the manager's decision process; a production function which mathematically simulates the system activity; and a constraint function which simulates the real bound placed on the systems' operation. The variables in each part of the model depend on the manager's current purpose; for example, minimizing cost subject to maintaining an activity level or maximizing output subject to a budgetory limit. In the NRMC case, not only is the objective function undefined, there is no agreement on the output measure. The model, then, must be stated in terms of variables which can be used either individually or in various aggregations to examine the consequences of different definitions of output and with different objective functions.

Analytic models are normally developed to be one of the tools used by the analyst himself during the course of his enquiry. In the case of the NRMC model an additional goal was set — to provide a model which could be used by management for self-evaluation and analysis in daily decision-making. The requirements for the model in meeting this goal are that it be relatively simple, clearly formulated and carefully explained.

Linear programming techniques[1] are particularly useful for initial studies of complex systems because of their

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[1]A brief description of linear programming models is provided in Appendix I.

inherent simplicity. While the overall model can be quite complex each equation is easily formulated and understood. For the NRMC model this characteristic is particularly useful in achieving the flexibility desired. As a result of these considerations the following general scheme for the model evolved:

1. For each patient category considered a vector of resources used is defined.
2. Total demand on resources is developed from linear computations on the resource vectors and total patient counts.
3. Availability of resources is computed by linear calculations on the number of personnel available.
4. Linear constraints are formulated to simulate the existing physical and policy restrictions on patient loads.
5. Costs are computed for resources used and for resources available.
6. Comparisons are made to determine what constraints are in effect and where excess resource capacity exists.

C. ANALYSIS OF NRMC STRUCTURE AND OPERATIONS

In the initial modeling effort it was desired that the more important factors be incorporated first. A review of the Fiscal Year (FY) 1972 budget was conducted to isolate significant expense areas. During the review it became apparent that some budget categories were inadequately defined for the present analysis. The significant results of this review are discussed below. Budget data is taken from the FY 1973 Budget Estimate [Ref. 9] prepared by Oakland Naval Hospital; data on numbers of personnel from the Personnel Manning Document, Oakland Naval Hospital [Ref. 7].

Table 1 shows the FY72 budget breakdown by the line items used Navywide for the final Navy budget. Table 2 summarizes the same data by grouping similar line items. In both tables an estimate for capital equipment expenditures (reported and funded separately from the operating budget) in the amount of 1.5 million dollars has been added for completeness. It is readily apparent that personnel categories are the greatest source of expense, accounting for almost 76% of the total budget (and 81% of the operating budget).

TABLE 1

FY72 BUDGET BREAKDOWN BY LINE ITEM

item	amount	%	cumulative %
military personnel	9,295,000	45.11	-
civilian personnel	6,275,915	30.51	75.62
supplies	2,157,595	10.45	86.17
capital equipment	1,500,000	7.28	93.35
purchased services	603,400	2.93	96.38
utilities/rent	366,520	1.78	98.16
consummable equipment	196,385	.95	99.01
communications	116,125	.56	99.67
travel	72,935	.35	99.92
miscellaneous	17,105	.08	100.00

TABLE 2

BUDGET PERCENTAGES BY GROUPED LINE ITEMS

group	%
personnel	75.97
equipment	8.23
supplies	13.38
other support	2.42

Table 3 shows the FY72 budget divided into the categories prescribed by the program budgeting system currently used in the Navy. The estimate for capital expenditures is

deleted to avoid biasing the data since information was not available to allocate capital expenditures across program elements. Approximately 78% of the budget is consumed in performance of the hospital's main mission — health care delivery. Table 4 provides the breakdown by line item of the main mission area FY72 expenditures. Almost 85% of these expenditures are for personnel so that it would appear the employment of medical care personnel consumes almost 69% of the operating budget.

TABLE 3

SUMMARY OF BUDGET BY FUNCTION

item	amount	%	total %
main mission	14,945,000	78.20	—
administration	1,098,395	5.75	83.95
property maintenance	1,033,500	5.42	89.37
utilities	384,445	2.05	91.42
base service	364,290	1.91	93.33
engineering support	362,625	1.90	95.23
personnel support	340,810	1.78	97.01
supply	315,945	1.65	98.66
transportation	182,315	.95	99.61
RDT & E	44,630	.23	99.84
minor construction	30,025	.16	100.00

TABLE 4

MAIN MISSION AREA BUDGET BY LINE ITEM

line item	amount	%	total %	% of line item total*
military personnel	8,390,815	56.10		90.2
travel	69,495	.46	56.56	95.8
total milpers	8,460,310	56.56		
civilian personnel	4,244,410	28.36		67.6
total personnel	12,704,720	84.92	84.92	
supplies	1,940,830	12.98	97.90	90.0
consummable equipment	184,215	1.23	99.13	93.8
purchases services	112,010	.75	99.88	18.5
miscellaneous	3,225	.12	100	18.8

*this column gives the % of the total line item expense accounted for by the main mission portion of that line item

Direct comparisons of the personnel data in the manning document with that in the budget estimate are difficult because of the time difference in the data. The personnel data in the manning document is the on-board count on 31 December 1971 while the budget estimate reports (or estimates) the man-years employed during the fiscal year, including allocation for persons employed only part of the year. Compounding the problem in the period under study is the personnel turbulance caused by abatement of the Vietnam conflict. Nevertheless it is possible to make close enough comparisons for the present purpose. Table 5 presents the military and civilian man-year data for FY72 as reported in the budget estimate. Table 6 was derived from the manning document by consolidating similar system components by functions approximating those used in Table 5.

There are significant differences in these figures. The total personnel employed in areas that would appear to make up the main mission area are reasonably close. However, there is little correlation between the remaining groups in the two tables. Table 7 provides a breakdown of personnel into broad categories based on the job description and job codes listed in the manning document. For those areas where there are jobs listed for medical personnel which are clearly administrative, the number is listed to assist in analyzing the personnel makeup of the main mission area.

TABLE 5

MAN-YEARS EXPENDED FY72

area	military	civilian	total	% total man-years
main mission	943	364*	1307	77.3
administration	56	144	200	11.8
supply	7	23	30	1.8
base operations	27	6	33	1.8
transportation		12	12	.8
utilities		4	4	.2
general engineering	4	16	20	1.2
maintenance		38	38	2.3
construction				
personnel support	34	3	37	2.3
RDT & E	9		9	.5
total	1080	610	1690	100.0

*data rounded down to integer values

TABLE 6

HOSPITAL MANPOWER - 31 DECEMBER 1971

area	military	civilian	total
medical services	362	78	440
interns	26		26
nursing service	368	118	486
dental service	31	5	36
lab, Xray & pharmacy	123	31	154
students & instructors	90		90
subtotal	1000	232	1232
central staff	23	14	37
military personnel	20	7	27
data processing		10	10
patient affairs	17	44	61
public works	4	87	91
security	30	9	39
special services	17	1	18
operating services	19	81	100
food service	3	95	98
fiscal/supply	14	42	56
RDT & E	5	10	15
total	1152	632	1784

TABLE 7

MANPOWER BY GENERAL CATEGORY

	on board	number in administration
military		
medical corps	222	
nursing corps	136	
medical services corps	39	13
dental corps	17	
hospital corps - specialized	174	
hospital corps - general	555	70
others	49	49
subtotal	1192	132
civilian		
nurses	117	
medical specialties	53	
clerical	132	132
other	297	297
subtotal	599	429
total	1791	561

Using the data in Tables 5-7 it is possible to visualize various mixes of personnel and areas that could define the main mission area as reported in the budget estimate. Rigorous prosecution of this course of study is unnecessary since it is readily evident from the data that any definition will contain a mixture of personnel which is not suitable for functional analysis of hospital operations. The concepts represented by the data are suitable for management of overall resources by central Navy management but inadequate for the present analysis. It is not the current purpose of this project to investigate adequate program budgeting systems for health facilities, however, a model suitable for management use must be capable of such analyses.

The results of this brief summary provide guidance on formulating the model. Personnel is the greatest single factor in the 'production function' of the hospital. In the NRMC, almost 90% of the personnel are included in the two general areas of health care delivery and administration. The employment of personnel in these areas is not clear. The initial effort, then is directed at analyzing the interaction between patient load and personnel resource consumption. Areas that individually account for small percentages of operating cost will either be considered fixed or modeled as simple linear cost equations on patient load; costs, other than personnel, in the modeled areas will be treated likewise.

D. FUNCTIONAL STRUCTURE OF NAVY REGIONAL MEDICAL CENTER

The present organizational structure of Oakland Naval Hospital is detailed in Appendix II. The NRMC is organized in the same manner; the head of the hospital unit acting as head of the corresponding NRMC unit, in most cases. As discussed above, this organization is not suitable for the present model, therefore an organization by functions is proposed. Recognizing the need to retain at least the basic units of the present organization in order to maintain credibility at the operating level, it was decided to reorganize the present units along functional lines. This procedure is neither a rigorous application of program budgeting technique nor is it entirely satisfactory in the long range

because the present units are not all homogeneous in function, however, it is adequate for the initial analysis.

The first step was to analyze the general nature of operations at the dispensaries to determine whether there existed similarities allowing simplification of the model. Data from the Medical Services Report [Ref. 8] for each dispensary and the hospital covering the period January through March 1973 was reviewed. Table 8, showing the general workload distribution at each location, is provided for general information. Table 9 presents the detailed breakdown of the outpatient visits reported in Table 8. The dispensary at San Francisco Naval Shipyard is deleted due to its imminent closure. Table 10 catalogs the patient distribution by general groups. It is apparent from the diverse nature of the workload and patient distribution that a model treating personnel resources in detail must incorporate each dispensary independently. The travel distance from the hospital to each dispensary is widely variant also and this factor is important in considering partial allocations of central resources to satellite facilities.

Seven levels of activity are defined based on the roles the various units play in providing medical care to patients. At this stage the assignment of units to each defined level is arbitrary; the purpose being to guide construction of the model. Further analysis may require more and/or finer definitions of levels and reassignment of units. It is traditional to consider patient care as either inpatient or

TABLE 8

NRMC WORKLOAD DISTRIBUTION THIRD QUARTER FY73

Services	Hosp	Ala	TI	Val	MI	Mof	Skgs	Conc	Stk	NSC
outpatients	74098	34893	20019	7867	21464	29990	1652	6263	2949	2072
limited services	28932	7515	11882	1520	49438	8859	30	86	149	1017
total	103030	42408	31901	9387	70902	39849	1682	6349	3098	3089
laboratory	304220	24562	18535	4972	10800	12923	802	8267	1510	1782
pharmacy	115594	30582	17998	461	19113	37975	1854	7742	4874	871
X-ray	43918	4432	9539	1371	5609	7054	121	2730	760	876
physicals	524	2341	5957	1528	971	853	64	473	179	442
immunizations	3301	5298	5000	252	3501	2928	289	249	181	514

KEY TO ABBREVIATIONS IN TABLES 8, 9 and 10:

Hosp = Oakland Naval Hospital
Ala = Alameda
TI = Treasure Island
Val = Vallejo
MI = Mare Island
Mof = Moffet Field
Skgs = Skaggs Island
Conc = Concord
Stk = Stockton
NSC = Supply Center, Oakland

TABLE 9

DISTRIBUTION OF OUTPATIENT VISITS FIRST QUARTER FY73

Clinic	Hosp	Ala	TI	Val	MI	Mof	Skgs	Conc	Stk	NSC
allergy	3345	4	475			1816				
cardiology	745					22				
dermatology	3173	30			131					
emergency room	5614	10210	789		3151	3962				
General medicine	3670	4707	12955		12045	65				
General practice	15221	12027		5375	4403	17120	1652	6263	2949	2072
General surgery	2439	146			120	148				
Gynecology	3573	750	597		483	66				
Obstetrics	2919	503								
Opthamology	7533	1080	2767			2169				
Orthopedics	4723	662	240		14	297				
Otolaryngology	5265	137			111	119				
Pediatrics	8064	3763	1438		841	3573				
Physical Therapy	2529	880	388	2492	162	585				
Psychiatry	2497	39	370		3	48				
Psychology	304	111								

The following clinics were in operation only at the hospital:

Chest	408	Neurosurgery	480
Endocrinology	238	Occupational Therapy	66
Gastroenterology	393	Proctology	176
Hematology	227	Thoracic surgery	145
Neurosurgery	709	Urology	1740

TABLE 10

DISTRIBUTION OF PATIENTS BY TYPE

Type	Hosp	Ala	TI	Val	MI	Mof	Skgs	Conc	Stk	NSC
Active duty	16.1	26.9	66.6		23.3	32.6	38.3	19.3	21.6	6.5
Dependent	33.3	35.2	20.6		59.2	34.3	47.2	28.8	29.4	1.5
Retired	16.7	2.2	6.0		9.4	8.9	2.4	7.8	25.4	1.0
Dependent	32.4	2.7	3.2		6.2	22.3	11.3	28.4	14.2	
Other	1.5	33.0	3.6	100	1.9	1.9	.8	15.7	9.4	91.0

Note 1: data is the percentage by type for the total outpatient visits at each location

Note 2: 'Other' includes civilians of various categories

outpatient treatment. This distinction is maintained in the model only by the division of patient categories, to be discussed after the formulation of the model. The two levels defining direct patient care activity in the proposed structure appear, from the units listed for each, to maintain this division; however a considerable amount of care for ambulatory inpatients is provided in areas traditionally considered outpatient facilities. To emphasize this the two areas have been named 'primary' and 'secondary' instead of the traditional terms. It is important to properly account for total usage of each area to provide the correct information for decisions on physical resource allocations.

1. Definitions of Functional Levels

a. Primary Treatment - incorporates those areas where physicians offices, examining rooms and clinic facilities are located.

b. Secondary Treatment - areas, not included above, where extensive treatment is conducted. These areas are more specialized in nature and are detached from physicians' offices. Inpatient wards are included here for reasons discussed in the preceding paragraph.

c. Treatment Support - areas included in this level are equipped and designated for specialized treatment procedures or services.

d. Diagnostic Support - especially equipped areas to which patients or specimens are sent for specific analytic procedures.

e. Non-treatment Support - the functions of areas included here may be medical or non-medical in nature but do not involve direct medical care. They provide direct support to medical functions.

f. Medical Administrative Support - these areas perform administrative functions dealing primarily with medical care, as opposed to organizational administration.

g. General Support - the remaining support units in the organization exclusive of those included in Base Support.

h. Base Support - those areas providing support to the Naval Facility per se rather than to the hospital specifically.

2. Proposed Functional Organization

Primary Treatment

allergy	military sick call
cardiology	neuropsychiatry
dental	neurosurgery
dermatology	obstetrics/gynecology
ear-nose-throat	opthamology
emergency room	orthopedics
family practice*	pediatrics
general practice	surgery
internal medicine	urology

* when added

Secondary Treatment

cardiac care unit	operating suite
delivery rooms	nursery
labor rooms	surgical intensive care
medical intensive care	inpatient wards*

* listed by service

Treatment Support

aural-speech therapy
drug rehabilitation
occupational therapy
pharmacy
physical therapy
prosthetics lab
radiation therapy

Diagnostic Support

EEG
laboratory
radiology (less therapy)
EKG
nuclear medicine

Non-treatment Support

central sterilizer
chaplains
food service
medical library
medical repair
nursing administration

Medical Administration

admissions
medical records
outpatient administration
patient affairs

General Support

clinical investigation center
data processing
hospitalman school
central administration
preventive medicine unit
operating services
supply/fiscal

Base Support

housing
maintenance/utilities
public works
security
special services
transportation

E. NOTATION SYSTEM

Developing familiarity with the notation of a complex model is difficult even for the experienced analyst. In order to minimize this problem a systematic notation scheme was developed which also serves as an index to variable definitions. This scheme is diagrammed in figure 1.

(e) / (c) / (d) / (a) / (b)

figure 1

The following definitions of the parts of the notation are provided:

(a) Two letters are used to identify the resource; for example, DR indicates physicians. The codes used are defined as they arise in the text of the model.

(b) Up to three subscripts i, j, and k are used to indicate:

i - subclasses of the resource
j - location
k - patient category

(c) A one letter code indicates what quantity is being measured with regard to the resource; for example, ADR indicates available time of physicians. The following codes are used:

A - availability
B - budget
C - personnel constraints
D - demand
D_s - demand defined in submodel
F - physical capacity constraints
M - derived constraints (defined in text)
N - number of personnel
O - overtime or backlog
R - resource vector
R_s - resource variable used in submodel
$ - cost

(d) Computations with subscripted variables often require summation over the range of one or more of the subscripts. One or two letters preceding the resource designator serve to identify the subscript summed over and thus indicate how the remaining subscripts are to be read. This is necessary to avoid confusion in use, where numbers replace letters as subscripts. Absence of this code indicates subscripts are read in order, i.e. i; i,j; or i,j,k. Thus only the following special codes are needed:

I - indicates remaining subscripts are j,k
IJ - indicates remaining subscript is k
IK - indicates remaining subscript is j
J_h - indicates summation over hospital locations
J_d - indicates summation over dispensaries only

(e) A modifier Δ_ℓ indicates an increment of the variable named that is generated separately in a submodel. The values of ℓ are defined in the submodel sections.

The following examples are provided to assist interpretation of the notation. For generality let X denote any resource variable.

$DX_{i,j,k}$	=	total demand on subclass i of resource X in location j by all patients in category k
$DX_{i,j}$	=	total demand on subclass i of resource X in location j by the sum of all patients
DX_i	=	total demand on subclass i of resource X by the sum of all patients in all locations
$DIX_{j,k}$	=	total demand on resource X as a whole in location j by the sum of patients in category k
$DIJX_k$	=	total demand on resource X as a whole over all locations for all patients in category k
DX	=	total demand by the system on resource X
$\Delta_\ell DJ_hIX_k$	=	the amount of demand on resource X generated in submodel ℓ over all hospital locations by the sum of patients in category k

III. THE RESOURCE VECTOR

A. GENERAL DISCUSSION

The total resource vector is simply a list of all the system resources whose usage is of interest at a specific point in time. There is a resource subvector for each category of patient defined in the model. These patient categories are discussed in section XI. The purpose of this section is to propose the resource variables for the initial model, define them and outline their measurement. Later sections provide for manipulating the resource vectors to produce cumulative results of analytic interest.

For each patient category the resources used by representative patients of that category must be identified. The initial model uses the average amount of resource consumed per patient in the resource vector. Later studies could use random variables on as many resources as considered pertinent for their purposes, without changing the model structure. Each variable is an aggregate measure of resource usage which means that, for example, if four nurses spend ten minutes each with a patient then forty nurse-minutes are consumed. While the resource vector contains several hundred variables it must be recognized that only a few will be used by a particular patient category. Formulating the vector in general terms provides for ease in understanding and facility in adding or deleting both patient categories and resource variables as desired for later management purposes.

While the model was developed for use at the NRMC, Oakland the discussion in the ensuing sections is general in nature so that other health facilities can adapt it for their own use. For this reason, there are variables defined which may not be pertinent at a given facility. These variables do not affect the formulation of the model and may be simply deleted where appropriate. This being the initial modeling effort, not all resources appear specifically in the model. Those that do not are considered part of fixed costs (discussed in section IX) for the present.

B. RESOURCE VARIABLES — CODES

1. Subscripts

a. i — subclassifications of primary variables. These are defined separately for each variable and are listed below.

b. j — location codes

01. General practice clinic
02. Emergency room
03. Dermatology - primary
04. Medical Service - primary
05. Neuropsychiatry - primary
06. Obstetrics/gynecology - primary
07. Opthamology - primary
08. Orthopedics - primary
09. Otolaryngology - primary
10. Pediatrics - primary
11. Surgical - primary
12. Urology - primary
13. Neurology - primary

14. Dermatology - secondary
15. Medical service - secondary
16. Neuropsychiatry - secondary
17. Obstetrics/gynecology - secondary
18. Opthamology - secondary
19. Orthopedics - secondary
20. Otolaryngology - secondary

21. Pediatrics - secondary
22. Surgical - secondary
23. Urology - secondary
24. Neurology - secondary
25. Nursery

26. Dispensary - Naval Supply Center, Oakland
27. Dispensary - Alameda
28. Dispensary - Treasure Island
29. Dispensary - Skaggs Island
30. Dispensary - Vallejo
31. Dispensary - Mare Island
32. Dispensary - Moffet Field
33. Dispensary - Concord
34. Dispensary - Stockton

c. k — patient categories (see section X)

2. Variables

a. $RDR_{i,j,k}$ — physician time

subclassifications

1. Dermatologist
2. General Practitioner
3. General Surgeon
4. Internist
5. Neurologist
6. Neurosurgeon
7. Obstetrician/gynecologist
8. Orthopedic surgeon
9. Pediatrician
10. Plastic surgeon
11. Psychiatrist
12. Psychologist
13. Thoracic surgeon
14. Urologist

b. $RDS_{i,j,k}$ — resident/intern time

subclassifications

1. Internist resident
2. OB/GYN resident
3. Orthopedic resident
4. Pediatrician resident
5. Psychiatrist resident
6. Surgical resident
7. Urologist resident
8. Intern

c. $RNR_{i,j,k}$ – nurse time

<u>subclassifications</u>

1. Registered nurse
2. Licensed nurse
3. Student nurse
4. Nurse's aide

d. $RPM_{i,j,k}$ – paramedic time

<u>subclassifications</u>

1. all paramedic personnel

e. $RMA_{i,j,k}$ – Medical assistant time

<u>subclassifications</u>

1. All medical assistants. Analysis may indicate the desirability of a detailed breakdown.

f. $RMR_{i,j,k}$ – medical record preparation time

<u>subclassifications</u>

1. physician's time
2. processor's time

g. $RLB_{i,j,k}$ – laboratory test units

<u>subclassifications</u>

1. Biochemistry
2. Blood Bank
3. Hematology
4. Microbiology
5. Pathology
6. Urinalysis
7. Morgue

h. $RXR_{i,j,k}$ – X-ray test units

<u>subclassifications</u>

further analysis is required with expert help to designate appropriate subclassifications in this area. In addition to nuclear medicine and special procedures, the common requests should be included separately.

i. $RPH_{i,j,k}$ – pharmacy units issued

<u>subclassifications</u>

further analysis is required with expert help to designate appropriate subclassifications in this area. Broad groups such as anti-biotics should be designated.

j. $ROR_{i,j,k}$ – operating room time

<u>subclassifications</u>

1. General operating room
2. Orthopedic operating room
3. Neurology operating room
4. recovery room

k. $RST_{i,j,k}$ – surgical team time

<u>subclassifications</u>

1. General surgeon
2. Plastic surgeon
3. Thoracic surgeon
4. Orthopedic surgeon
5. neurosurgeon
6. surgical resident
7. operating room technical supervisor
8. operating room team member
9. operating room nurse
10. anesthesiologist
11. anesthetist nurse

l. $RTH_{i,j,k}$ – therapy facility time

<u>subclassifications</u>

1. audio-visual therapy
2. physical therapy
3. occupational therapy
4. radiation therapy

m. $RSF_{i,j,k}$ – special facility time

<u>subclassifications</u>

1. Medical intensive care unit (MICU)
2. Surgical intensive care unit (SICU)
3. Cardiac care unit (CCU)
4. Labor room
5. Delivery room

n. $RFA_{i,j,k}$ — facility time

subclassifications

this variable measures time at locations j and thus there are no subclassifications on i.

o. P_k — the number of patients of category k.

While not a part of the resource vector, this term is defined here for convenience.

C. RESOURCE VARIABLES - DEFINITION AND MEASUREMENT

Data for some of the resource variables defined is not currently available. In some cases the desired information can be derived from existing records; in others raw data must be gathered and processed. Each variable is defined in this section and where current records are available their use is indicated. The term 'observe and verify' used in this section indicates the necessity for application of appropriate random sampling and statistical estimation techniques in obtaining values for the variables. For the benefit of health facility personnel unfamiliar with such techniques Appendix I describes procedures which will provide useful estimates without computational difficulty.

The information on records used in this section was derived from studies at Oakland Naval Hospital. The records at hospitals of other military branches and at civilian facilities may differ. In these cases the variable description will indicate the appropriate data.

1. RDR - Physician time

a. Definition: The average amount of time physicians devote to treatment of an individual patient of a given category. This time commences when the physician commits his attention to the patient and ends when the physician is free to treat another. Included in this variable are the time to write medical record entries, write prescriptions, review X-ray and laboratory results and other similar treatment oriented actions. In cases where physicians visit patients, as for example in ward rounds, the transit time from one patient to the next is included. The guiding principle in accounting for personnel time, as it is in all personnel time measures in the model, is that all the time a physician is occupied due to a treatment, so as to be unavailable for other patients, must be charged to the patient in treatment. Senior residents are considered as physicians in this model.

b. Measurement: There is little data available which is suitable for use in this model. Observe and verify.

2. RDS - Resident/intern time

a. Definition: This variable is treated exactly as physician time. The purpose of separating the two is to provide a variable for use in estimating training costs and benefits.

b. Measurement: Observe and verify.

3. RNR - Nurse time

a. Definition: This variable accounts for the cumulative total of time increments added to each nursing task associated with the care of a patient in a given category.

b. Measurement: Observe and verify. Care should be exercised to include only those tasks which by hospital policy are assigned to the nursing staff. A review of current tasks may indicate some which are performed (or not performed) due to personnel shortages in other areas. These should be accounted for under the appropriate variable to provide accurate information on resource consumption.

4. RMA - Medical Assistant time

a. Definition: Medical assistants are defined in this model as personnel with specialized medical training who directly assist in treatment of patients. Navy Hospital Corps personnel performing clerical functions are not included in this category. The variable measures the cumulative total of time increments added to tasks associated with treatment of a patient of a given category.

b. Measurement: Observe and verify.

5. RPM - Paramedic time

a. Definition: Paramedics are non-physician personnel specifically trained for and assigned to well defined functions historically performed by physicians. The definition of physician time is applicable here.

b. Measurement: Observe and verify.

6. RMR - Medical record preparation time

a. Definition: The time to write, process and review the medical entries associated with a particular patient category are included in this variable. This variable is included as an example of how a particular problem of interest

might be studied in the model framework. The current emphasis on more efficient use of physician time suggested this example as appropriate. Since this variable is an increment to be subtracted from physician time, nothing is lost by deleting it from the model.

b. Measurement: Observe and verify. Only the time to perform each task associated with the medical record entry is measured. Waiting time between steps is not counted. The time for each step must be estimated using the current technology. This is important because the way a new system is evaluated is to change this parameter appropriately and then investigate the costs of a new technology versus the benefits derived.

7. <u>RLB - Laboratory test units</u>

a. Definition: This variable indicates the number of test samples for each subclassification sent to the laboratory for a patient of a given category. The usual value of these variables will be 0 or 1, however, in cases where a time series of samples is sent this variable accounts for the number per day. This variable is used as an input to a submodel.

b. Measurement: Existing records list the test ordered, the ward or clinic ordering, and the patients name. This information plus data on the beds occupied by ward and the number of clinic visits can be used to derive the values for this variable. As an alternative, properly structured

substitute records could be used for a study period to derive the necessary data.

8. RXR - X-ray test units

a. Definition: For each subclassification a 0 or 1 will indicate whether or not a particular patient category utilizes that procedure. The variable is an input to a submodel.

b. Measurement: The procedure outlined for the laboratory applies since the same records exist.

9. RPH - Pharmacy units issued

a. Definition: For each subclassification the variable indicates whether or not prescriptions normally issued to a patient of a given category fall in that classification. The variable is an input to a submodel.

b. Measurement: Current records are not suitable for derivation of the necessary values. Temporary location-coded prescription forms are needed to generate a data base.

10. ROR - Operating room time

a. Definition: This variable indicates the time an operating room is committed to the treatment of a patient of a given category. Set up, procedural and clean up time is included. Time in the recovery room is measure from departing the operating room until departing the surgical suite if the recovery room is utilized; otherwise it is zero.

b. Measurement: Observe and verify.

11. <u>RST - Surgical team time</u>

a. Definition: For each subclassification this variable includes the time to prepare for, execute, clean up from and record the surgical procedures performed on a patient of a given category. For personnel whose time is also accounted for in other variables the time recorded on the surgical team is not included in those other variables. Preparation time is meant to include only the time devoted to preparing specifically for the treatment of an individual patient.

b. Measurement: Observe and verify.

12. <u>RTH - Therapy facility time</u>

a. Definition: The time a patient occupies a therapy facility, from arrival to departure, is included in this variable which is used as an input to a submodel.

b. Measurement: Observe and verify.

13. <u>RSF - Special facility time</u>

a. Definition: The time the resources of a special facility are used by a patient of a given category are indicated in this variable. This time includes set up, use and clean up time. The variable is an input to a submodel.

b. Measurement: Observe and verify at those facilities not normally occupied for full days by a given patient.

14. <u>RFA - Facility time</u>

a. Definition: This variable records the time a patient of a given category physically occupies a treatment location. The primary purpose of the variable is to account

for bed days in inpatient care areas, however it can also be used in submodels of each location to examine in detail the medical support structure. This is not done in the initial model.

b. Measurement: Observe and verify.

IV. THE DEMAND EQUATIONS

A. GENERAL DISCUSSION

The k resource vectors, one for each patient category, contain the basic data relating treatment of an average individual patient to resource consumption. Given a set of patient loads P_k, various quantities of analytic interest can be derived by appropriate mathematical manipulation. The quantities of particular interest in the current study are developed below. The techniques employed are equally suitable for generating other quantities needed by management for a specific study. For simplicity, the equations are illustrated in terms of one resource as an example. In writing out the full model there will be one equation of each type for each resource variable used. In writing the specific equations care must be exercised to ensure the proper range for each subscript in the equation is specified.

Following the exposition of the general demand equations various possible treatments of those variables which are inputs to submodels or which involve personnel in training are discussed.

B. THE GENERAL DEMAND EQUATIONS

In all of the quantities defined below the increments of demand added from submodels is excluded. These increments are accounted for in the sections dealing with constraint and cost equations.

1. <u>Demand on a subclass by a patient category, k</u>

a. At a specific location, j:

Multiplying the kth resource vector, R_k, by the number of patients of category k, P_k, has the effect of multiplying every component variable of that vector by P_k. Thus, the amount of dermatologist time required in the primary treatment area by P_k patients of category k is given by:[2]

$$(1) \qquad DDR_{1,12,k} = P_k * RDR_{1,12,k}$$

b. Over all locations:

The demand generated for dermatologist time in the whole system by the P_k patients of category k is found by summing the demand at each location. This is written:[3]

$$(2) \qquad JDDR_{1,k} = \sum_j P_k * RDR_{1,j,k}\ , \quad j = 1 - 34$$

c. At the hospital only:

This variation of Equation (2) to generate the demand at the hospital vice the whole system is provided as

[2]the symbol * will be used throughout to denote multiplication

[3]The symbol Σ indicates the summation of a string of variables. The use of this symbol in equations is explained in Appendix I.

a one time example of how to modify the various equations in the model to provide additional information:

$$(3) \qquad {}_{J_h}DDR_{1,k} = \sum_j P_k * RDR_{1,j,k} , \quad j = 1 - 25$$

2. Demand on a subclass by total patient load

a. By location:

This quantity is generated by summing the demand of each patient category on the desired variable. For example, the total demand on dermatologists in the primary treatment area is written:

$$(4) \qquad DDR_{1,12} = \sum_k P_k * RDR_{1,12,k} , \quad k = \text{all values}$$

b. Over all locations:

Summing the total demand at each location generates the total demand. Thus the total system demand for dermatologists is written:

$$(5) \qquad DDR_1 = \sum_j \sum_k P_k * RDR_{1,j,k} , \quad \begin{array}{l} j = 1 - 34, \\ k = \text{all values} \end{array}$$

3. Demand on a primary variable by a patient category, k

a. By location:

The primary variable demand is found by summing over the subclasses of that variable. Thus, the demand for physicians in the medical service secondary area generated by the number of patients in category k is written:

(6) $$IDDR_{15,k} = \sum_{i} P_k * RDR_{15,k}$$

b. Over all locations:

The systemwide demand on a primary variable by the patients of a category is generated by summing the location demand over all locations. The demand for physicians by the number of patients in category k is written:

(7) $$IJDDR_k = \sum_{i} \sum_{j} P_k * RDR_{i,j,k}\ ,\quad j=1\text{-}34,\ i\text{-}1\text{-}14$$

4. <u>Demand on a primary variable by total patient load</u>

a. By location:

The demand by patient category is summed over all categories defined. Thus, the demand on physicians in, for example, the emergency room is written:

(8) $$IKDDR_2 = \sum_{i} \sum_{k} P_k * RDR_{i,2,k}\ ,\quad i=1\text{-}14,\ k=\text{all values}$$

b. Over all locations:

The total amount of a resource required by all patients treated is generated by summing the location demand over all locations and in the case of physicians is written:

(9) $$DDR = \sum_{i} \sum_{j} \sum_{k} P_k * RDR_{i,j,k}\ ,\quad i=1\text{-}14,\ j=1\text{-}34,\ k=\text{all values}$$

C. VARIATIONS IN THE TREATMENT OF SUBMODEL INPUTS

Most of the resource variables dealing with treatment and diagnostic support are treated in the resource vector as inputs to a submodel. There are many possible approaches to using these variables depending on the purpose of the analyst and the computational resources available. Each different approach requires different cost equations and coefficients. Three major variations are discussed here to illustrate the possibilities. The laboratory is used as a representative example.

The decision on how to model these support areas is made primarily on the basis of how important the usage of individual resources at the support level is to the analysis at hand. If the problem does not require a detailed knowledge of how the support resource usage varies it is sufficient to use the general demand equation directly. The cost equation in this case will have coefficients stated in terms of the total cost to operate the support facility. For the laboratory there would be six variables giving the total demand for each of the six types of tests. The cost coefficients would be stated in terms of cost per test. These equations, of the form to be discussed in section IX, would be included with the other cost equations and a submodel would not be necessary.

If the analyst is interested only in one or two resources used in the support structure and is content to lump the rest together as discussed above then the resource vector can be

modified to incorporate these. In the laboratory, for example, if it were of interest only to analyze the demand for pathologists, the physician variable – RDR – could be modified by adding a subclassification 'i=15 – pathologist' and then treating the model as discussed in the first case above. In this case the cost coefficients would be modified by removing all of the costs of employing pathologists. Pathologist cost would be accounted for along with all the other resource costs as discussed in section IX.

In an initial analysis, such as this one, it is usually desirable to incorporate as much detail as possible until the effects of patient load variation on resource usage is understood and then to simplify the model for use by deleting the variables that do not contribute to the analytic effort. This objective is conventiently achieved with the use of submodels because each submodel is independent of the rest and can be modified or deleted altogether without affecting the others. This is essential in maintaining flexibility and minimizing confusion. It has the added benefit of allowing several people to work on an analysis simultaneously and yet independently. The detailed development and discussion of the submodels proposed for this study is contained in section V.

D. TREATMENT OF VARIABLES INVOLVING TRAINEES

Oakland Naval Hospital is a teaching facility with residencies in several medical specialties, an intern program and assorted schools for Hospital Corps personnel.

One of the major difficulties encountered by past efforts to define the output of health facilities has been in dealing with the dual mission of teaching facilities. Compounding the problem of defining output in terms of patient care is the fact that some of the resources utilized in treating patients are simultaneously receiving benefits in terms of the experience derived from the treatment of those patients. It is not the purpose of this report to propose solutions to this problem, however the model will be used for studying ways to quantify the training benefits separately from the patient care benefits. For this reason it was important to provide appropriate variables in the model for these studies which was done by creating separate variables for personnel in a training status. One question remains to be answered — how to decide between assigning resource demand to the student or the instructor. The answer to this question must depend on the policy of the hospital and further study is required before the specific approach for the NRMC model can be formulated. Two possible approaches are outlined below for illustration using residents as an example.

1. Divide the defined patient categories into groups such as the following:

Group 1:	patients are seen by residents, if available
Group 2:	patients are seen by a fully qualified physician
Group 3:	patients are seen by both residents and fully qualified physicians as a matter of routine
Group 4:	patients are seen by a physician, and a resident if available
Group 5:	There is no set policy.

The resource variable to be assigned the demand would then be chosen as follows:

Group 1: assigned to the resident

Group 2: assigned to the physician

Group 3: the time demand for each must be estimated

Group 4: treat as group 2 ignoring resident time

Group 5: assign the time to residents and let the constraint on resident time assign the excess to physicians

2. A different approach is to divide the patient load for a given category on a percentage basis determined from historical data or set by a policy decision. Estimate separately the time required for treatment by a resident and by a fully qualified physician. Multiply these estimates by the corresponding fractions and use these values in the resource vector. When multiplied by the total patient load for that category in determining the demand, the correct balance is automatically generated.

Whatever approach is used in a particular study it is essential that it be consistently used and well defined so that the effects of whatever assumptions are made can be analyzed.

V. SUBMODELS

This section develops in detail the submodels alluded to in previous sections. The designation R_s has been used for resource variables defined in these submodels because the subscripts are defined differently than in the main model. The distinguishing designator should aid in avoiding the confusion possibly created by this procedure. The first submodel is explained in detail. The discussion of succeeding submodels is more cursory where the explanations in the first apply.

A. LABORATORY SUBMODEL

Subscripts used in this submodel are:

i — laboratory areas as used in main model:

1. Biochemistry
2. Blood bank
3. Hematology
4. Microbiology
5. Pathology (less morgue)
6. Urinalysis
7. Morgue

ℓ — laboratory personnel categories:

1. Pathologist
2. Bacteriologist
3. Medical Technologist
4. Biochemist
5. Pathology resident
6. Technical assistants
7. Medical record processors

1. $R_sPL_{i,\ell}$ — personnel time

a. Definition — This variable accounts for the time demand on personnel of category ℓ per test unit in area i.

b. Measurement — For each area determine the common test procedures performed and the percent of the total

accounted for by each. Determine, for each test, the time increment required for each task in the test procedure. Compute a weighted average[4] time per test for each personnel category.

2. R_sRL_i – process time

a. Definition – the value of this variable is the processing time for the average test in area i.

b. Measurement – For each of the common tests used to compute personnel time, estimate the time that testing facilities are in use, assuming no pauses, utilizing the test procedure normally followed. Where batch testing is the common procedure this time should be the time to process one sample through the batch procedure. The weighted average of these times is used as the time to process the average test.

3. α – the death rate

a. Definition and measurement – the death rate of a hospital is normally expressed as a rate per 1000 inpatients. If data is available, a more accurate measure would be a weighted average of the death rate per patient category. In either case α is expressed as the death rate per inpatient.

4. β_i – batch processing factor

a. Definition and measurement – For each area i this variable is the weighted average number of samples per batch normally run for the common test procedures defined above.

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[4]Weighted averages are defined and illustrated in Appendix I.

5. γ – the autopsy rate

a. Definition and measurement – the percent of deaths for which autopsies are performed is recorded here.

6. δ_i – adjustment factor

a. Definition and measurement – this variable is an estimate of the percent of the time recorded for process and personnel time which must be performed on every sample, i.e. for which there is no saving due to batch processing.

Using these variables the demand on the resources of the laboratory can be computed. One example of each type demand equation is given for illustration. Different demand quantities can be generated simply by using different demand variables defined in section IV.

The demand for technical assistants in hematology as the result of total patient load is written:

$$(10) \quad D_s^{\cdot}PL_{3,6} = DLB_3 * R_sPL_{3,6} * \delta_3 + \frac{DLB_3}{\beta_3} * R_sPL_{3,6} * (1 - \delta_3)$$

This equation says that the total demand for technical assistant time in hematology generated by the overall patient load is equal to the number of samples (DLB_3) multiplied by the time per test required for each sample ($R_sPL_{3,6}*\delta_3$) plus the number of batches tested (DLB_3/β_3) multiplied by the time per batch ($R_sPL_{3,6} * (1 - \delta_3)$). In formulating the demand on

other laboratory personnel care must be taken to use the factor δ only where personnel are involved in performing batch testing.

For those personnel working in more than one area the equations must take this into account. For example the time demand for pathologists generated by the total patient load is written:

$$(11) \quad D_sPL_1 = DLB_1 * RPL_{1,5} + (\sum_k P_k) * \alpha * \gamma * RPL_{1,7}$$

where the range of k covers all inpatient categories

This equation says that the total demand for pathologist time generated by the overall patient load is equal to the demand generated in pathology plus the number of autopsies performed multiplied by the time per autopsy.

B. RADIOLOGY SUBMODEL

The manner in which the radiology department is modeled depends on the physical set up of the rooms and equipment. At Oakland Hospital rooms with different capabilities are designated for specific procedures. Thus in addition to the demand placed on personnel and equipment it may be of interest to study the demand on particular areas of the department. A procedure to accomplish this is developed in this submodel. As mentioned before, further study is required to divide the workload of radiology into suitable groups for the study. This submodel is complete except for these groupings.

Subscripts used in this submodel are:

i — X-ray procedures

to be developed

ℓ — radiology personnel categories

1. Radiologist
2. Radiologist resident
3. operating technician
4. processing technician
5. medical record processor

The following variables are defined:

1. $\underline{R_sPR_{i,\ell}}$ **— personnel time**

a. Definition — the time demanded of personnel type ℓ to perform procedure i. The same considerations previously discussed in measuring personnel time apply.

2. $\underline{R_sRR_i}$ **— facility time**

a. Definition — The time that a radiology facility is unavailable due to procedure i being performed is entered here. If a facility is normally set up for a specific procedure and the set up is changed only when a different procedure is performed then the set up time should be included in the variable. If this is not the case then an estimate of set up time adjusted for the probable number of times performed should be included.

The demand equations for personnel are written exactly as in the laboratory submodel. To generate the demand for special groupings the following example illustrates the procedure. Assume there are 10 procedures defined and three rooms set up as follows: Room 1 handles procedures 1-3; room 2 handles procedures 4-7; and room 3 handles procedures

8-10. Designating the demand on rooms by D_sRM_i, i=1,2,3 the equations would be written:

(12) $$D_sRM_1 = \sum_i (DXR_i * R_sRR_i) , \quad i=1-3$$

(13) $$D_sRM_2 = \sum_i (DXR_i * R_sRR_i) , \quad i=4-7$$

(14) $$D_sRM_3 = \sum_i (DXR_i * R_sRR_i) , \quad i=8-10$$

As in the laboratory submodel different quantities can be generated by changing DXR_i to toher patient category groupings.

C. PHARMACY

No submodel is proposed initially for the pharmacy.

D. PHYSICAL THERAPY SUBMODEL

The submodels for the therapy facilities are slightly different from the previous ones. Since each therapy submodel is identical the procedure will be explained here and only the variables defined for the others.

The following subscript is used:

ℓ — personnel categories

1. physical therapist
2. technical personnel
3. medical record processor

Variables are defined as follows:

1. <u>R_sPT_ℓ — personnel time</u>

a. Definition — the time demand on personnel category ℓ per treatment.

2. e_ℓ — adjustment factor

a. Definition — this factor is chosen so that when multiplied by the time a patient occupies the facility (RTH) the result is the amount of time the personnel of category ℓ spend with the patient. This factor need not be less than one since resource variables measure cumulative demand. For example two technical assistants each spending 90% of a patients occupying time with him would produce a factor e_2=1.8.

The demand for each personnel category is then simply computed as in the following example:

$$D_sTH_2 = e_2 * DTH_2 \tag{15}$$

If there is a wide variance in the time demand on a personnel category by different patient categories then the variables can be modified by adding a subscript m, for example $e_{\ell,m}$. The subscript m would indicate patient groups formed by dividing the patient categories by similar time demands.

E. OCCUPATIONAL THERAPY SUBMODEL

The subscript used in this submodel is:

ℓ — personnel categories

1. occupational therapist
2. technical personnel
3. medical record processor

The variables are denoted:

1. R_sOT_ℓ – personnel time

2. f_ℓ – adjustment factor

F. AUDIO AND SPEECH THERAPY SUBMODEL

The subscript used is:

ℓ – personnel categories

1. audiologist
2. technical assistants
3. medical records processor

The variables are denoted:

1. R_sAT_ℓ – personnel time

2. g_ℓ – adjustment factor

G. RADIATION THERAPY

Radiation therapy, due to the size of the facility is treated as a fixed cost in the initial model.

H. TRAINEE SUBMODEL

Whether or not training is included as a variable in the output function of the model for a particular study, it is necessary to account for the demand placed on personnel in an instructional role by the health care activity of trainees. This submodel, developed specifically for residents and interns, provides a first approximation to this demand and can be directly adapted to other training categories.

The treatment of patients by residents and interns results in a certain amount of consultation with qualified

physicians. Certain specific situations such as rounds in inpatient wards are accounted for in the resource variables as defined in the main model. These time increments are not to be included in estimating the values of variables in this submodel. Since much of the consultation may be handled by the senior residents it was decided to include them in the physician variable. Consultation in the context of this submodel means all forms of assistance, in person or by phone, directly related to the treatment of a specific patient whether provided on request of the trainee or as a matter of physician policy.

The following variable is defined:

1. <u>$h_{i,j,k,\ell}$ – the consultation factor</u>

a. Definition – this variable gives the percentage of the time a resident/intern of subclass ℓ spends treating a patient of category k which represents the consultation demand placed on a physician of subclass i in location j. The subscripts are those defined in the resource vector: i is the subclass of RDR; j is the location code; k is the patient category code defined in section X; and ℓ is the subclass subscript i of RDS.

b. Measurement – using a random sample of patients the estimate of each h is derived as follows:

$$h = \frac{\text{total minutes demand on physicians}}{\text{total treatment time of patients}}$$

The increment of demand on physician time generated from the submodel is then:

$$(16) \qquad \Delta_{\ell}DDR_{i,j,k} = \sum_{\ell} (DDS_{\ell,j,k} * h_{i,j,k,\ell}) \;, \quad \ell=1-8$$

I. SPECIAL FACILITY SUBMODELS

Special facilities as used in this model are specialized inpatient care areas staffed and equipped to more efficiently provide care that can be provided in regular treatment areas. The resources used, then, are generally the same however the intensity of use differs. The usage of these facilities is further distinguished in that 1) only a percentage of patients in a given category use them, or 2) they are used for only a portion of total treatment time. For this reason both intensive care facilities and delivery rooms are included in the category of special facilities.

The policy at Oakland Hospital is to count a ward bed as occupied for patients in special facilities. This presents problems in the model for the proper accounting of resource usage and special care must be taken not to count resources twice. Two approaches to this problem are suggested. The first estimates the difference in resource demand between the two areas and assigns this difference to users of the special facility. The second simply treats the special facility in the same manner as the main area and ignores the error generated. The first approach is better suited for

areas where patient stay is relatively long, while the second approach should not generate significant error if the stay in the special facility is short and the intensity of resource usage much greater in the special facility.

For each area a variable is needed for later use in capacity constraints. It seems natural for the capacity constraint in inpatient areas to be bed capacity. However, this may not be the case in special facilities. Since specialized equipment is generally needed in these areas the availability of some equipment may be exhausted before the temporary bed capacity of the area is exceeded. Thus, the constraint variable cannot be decided apriori without preliminary analysis in each area. Provision is made for this variable in the submodels without specifying which factor is to be used.

1. Intensive Care Areas

The following resource vector variables may be affected by operation of an intensive care facility:

$RDR_{i,j,k}$, $RDS_{i,j,k}$, $RNR_{i,j,k}$, $RMA_{k,j,k}$,

$RLB_{i,j,k}$, $RXR_{i,j,k}$, $RPH_{i,j,k}$

where i and j are specified as required.

The following notation is used to designate additional resource demands generated in a special facility :

Δ_ℓ – increment generated in special facility ℓ.

ℓ = 2 – medical intensive care
3 – surgical intensive care
4 – cardiac care
5 – labor room

The additional variables defined for the submodel are:

$m_{\ell,k}$ – the percent of patients in category k that use special facility ℓ estimated from historical data.

$LIM_{\ell,k}$ – the limiting factor variable. The variable value is the amount of time a patient in category k uses the limiting equipment of special facility ℓ. The time may be different from $RSF_{i,j,k}$ which will be used for bed capacity constraints and the cost equations. It includes all the time the limiting equipment is unavailable to other patients as the result of being used by a specific patient.

For each general demand equation an increment from these submodels is generated. For example, the addition to demand on a primary variable by a patient category k over all locations – equation (7) – would be written:

$$(17) \qquad \Delta_\ell DIJDR_k = \sum_i \sum_j P_k * m_{\ell,k} * \Delta_\ell RDR_{i,j,k}$$

where ℓ and the ranges of i and j are specified as appropriate. $\Delta_\ell RDR_{i,j,k}$ is the difference between resource usage at a special facility and the corresponding inpatient care area. The product $P_k * m_{\ell,k}$ is the number of patients using the facility.

In addition the demand equations for the limiting equipment are needed and are written:

$$(18) \qquad D_s LIM_{\ell,k} = P_k * m_{\ell,k} * LIM_{\ell,k} \quad , \quad \ell \text{ and } k \text{ specified}$$

Equation (18) is the demand by patient category. The demand over all patients is written:

$$(19) \qquad D_s LIM = \sum_k P_k * m_{\ell,k} * LIM_{\ell,k}$$

2. <u>Delivery Room</u>

The delivery room could be considered a special form of operating room and modeled in the same manner. Unless the initial analysis shows the delivery room area to be a bottleneck, however, it may be analytically more efficient to simply model a weighted average delivery. The weighted average delivery is computed first by patient category considering the delivery times for procedures performed on that category; then by taking the average over patient categories. The personnel times required are computed in the same manner. The delivery room is then modeled similarly to the therapy facilities.

The following variable is defined:

1. n_ℓ — adjustment factor. This factor when multiplied by delivery time yields the demand on personnel category ℓ, where ℓ is defined:

ℓ = 1 — obstetrician/gynecologist
2 — anesthesiologist
3 — OB/GYN resident
4 — registered nurse
5 — licensed nurse
6 — student nurse
7 — nurse's aide
8 — medical assistant

Using Δ_6 to indicate increments of demand generated in the delivery room submodel, the additions to demand are written as in the following example:

(20) $\Delta_6 DDR_7 = \sum_k (P_k * n_1)$, where k is defined over the range of patient categories using the delivery room. If it is not the case that all patients in a category use the delivery room then an additional variable indicating the percent that do is needed and is used as shown in the intensive care submodel, e.g. equations (17) - (19).

VI. PHYSICAL CONSTRAINTS

A. GENERAL DISCUSSION

The demand equations model the interaction between patients and resources at the health facility. Constraint variables are used to model limits on the resources available for patient care. These limits are imposed by several factors: 1) physical capacity; 2) equipment limitations; 3) the number of personnel employed; and 4) policy decisions on the use of available resources. Physical and equipment constraints are developed in this section; personnel constraints in Section VII.

Every location specified in the model has some limiting physical capacity to treat patients. The physical factor determining this capacity may be either the space allotted or the availability of some capital equipment. Analysis at each location is required to determine the actual factor and since it may change over time, the factor used should be specified to allow verification when desired. In the ensuing discussion, factors are hypothesized for each area. These factors are intuitive and require verification prior to using the model. Since the unit of the capacity variable is independent of the factor used, the formulation of the model does not change.

The data for the model is expressed in terms of units per day. Since the model will be used for varying time

periods, this fact has been accounted for in computing the constraint variables.

B. DEFINITION OF TERMS

1. Beds

The term 'beds' in the equations generating capacity variables means the number of beds assigned as a matter of policy for the type of operating conditions being modeled. This qualification is necessary because military hospitals define different capacities for normal operations and contingency operations such as wartime.

The term 'max # beds' is used for those areas where additional portable beds are provided as a matter of policy such as in a recovery room.

2. Rooms

The term 'rooms' is used for areas where an entire facility, such as a doctor's examining room, is occupied for a treatment procedure.

3. Limiting unit

The term 'limiting unit' is used where it is presently unclear what the limiting factor is. For example, in therapy facilities this factor could be a room or some special equipment.

4. Available time per unit

The term 'unit time' is used to indicate the amount of time per 24 hours that the factor is available. Set up and clean up time between patients has been accounted for in the resource variables. If a facility is subject to

routing maintenance requiring its unavailability, or if policy dictates partial operating periods, these facts should be reflected in reduced availability time.

C. CAPACITY CONSTRAINTS

1. Secondary Treatment Areas

(21) $$DIKFA_j \leq FFA_j \ , \quad j = 14\text{-}25$$

where:

$$FFA_j = (\#\ \text{beds in area } j) * (\#\ \text{days in period})$$

2. Primary Treatment Areas

(22) $$DIKFA_j \leq FFA_j \ , \quad j = 1,\ 3\text{-}13$$

where:

$$FFA_j = (\#\ \text{examining rooms}) * (\text{unit time}) * (\#\ \text{days in period})$$

Due to the nature of its operations there is no physical limiting capacity for the emergency room, j = 2.

3. Operating Suite

(23) $$DOR_i \leq FOR_i \ , \ i = 1\text{-}4$$

where:

$$FOR_i = (\#\ \text{operating rooms type } i) * (\text{unit time}) * (\#\ \text{days in period}),\ i = 1\text{-}3$$

and

$$FOR_4 = (\text{max \# beds}) * (\text{\# days in period})$$

4. <u>Therapy Facilities</u>

(24) $$DTH_i \leq FTH_i \ , \quad i = 1\text{-}4$$

where:

$$FTH_i = (\text{\# limiting units}) * (\text{unit time}) * (\text{\# days in period})$$

5. <u>Special Facilities</u>

(25) $$DSF_i \leq FSF_i \ , \quad i = 1\text{-}5$$

where:

$$FSF_i = (\text{max \# beds}) * (\text{\# days in period})$$

6. <u>Radiology</u>

(26) $$D_sRM_l \leq FRM_l \ , \quad l = 1\text{-}3$$

where:

$$FRM_l = (\text{\# rooms type l}) * (\text{unit time}) * (\text{\# days in period})$$

VII. PERSONNEL CONSTRAINTS

There are two basic types of personnel constraints of importance to the NRMC model. The first determines the maximum amount of time available for each personnel category. The second deals with management allocation of this time to meet competing requirements in various areas. These constraints are difficult to formulate because there is room for debate concerning the values of some of the parameters used in the equations, yet they are extremely important since apriori it would appear that personnel resources may be the bottlenecks to increased output. For these reasons this section develops in considerable detail the formulation and use of personnel constraints.

A. AVAILABILITY

1. General

Perhaps the most difficult problem in modeling the use of personnel resources in health facilities is determining the hours available for direct employment in health care delivery. The term 'direct employment' itself is ill-defined. In one sense all medically oriented activity of medical personnel could be considered direct employment since activity in one period which may not be directed specifically at a patient can be of benefit to patients treated in subsequent periods. In this model, activity not directly and immediately associated with the treatment of specific patients is counted separately from activity which is.

One difficulty is directly related to modeling personnel time — What time frame should be used in developing the data required? There are benefits and drawbacks to using annual, quarterly, monthly, weekly or daily data. The longer time periods tend to smooth out data value fluctuations found in shorter data periods but at a cost of reduced accuracy when long term data is extrapolated for short term use. An estimation procedure is proposed to minimize data collection efforts while providing a data bank with sufficient flexibility to be used over most time periods.

Physician availability is the most complex of the personnel categories and for this reason the development in this section is explained and illustrated in terms of physician time. All other personnel times are estimated by similar procedures deleting inapplicable details.

2. Definition of Terms

a. Working Hours — the time between first arrival and final departure from the health facility including all intervening time spent away from the facility except in the case of 'split-shift' workers.

b. Personal Time — that portion of working hours devoted to meals, personal business, etc... .

c. Professional Time — the portion of working hours devoted to study, various professional meetings, medical type boards and other similar professional activity not devoted to direct contact with patients. Activity included

in measuring this time should be only those required, not the time devoted to such activities due to the lack of patients.

d. Available Time — the increment of working hours available for treating patients. Available time is equal to:

WORKING HOURS - PERSONAL TIME - PROFESSIONAL TIME

3. Estimation Procedure

The procedure described here is intended for use by health facility personnel and is equally applicable for developing most of the data required for the model.

a. Determine for each subclass what activities are to be considered professional time. Transit time between hospital and dispensary for visiting physicians should be included in available time since the decision to split physician resources in this manner directly reduces available time. The initial determination can be amended as data collection proceeds and questionable areas are encountered.

b. Data is gathered by days, randomly selecting days of the week for each subclass.

c. Randomly select physicians from each subclass, the number depending on the manning level of the subclass and the data gathering resources employed.

d. For each sample, observe the working hours, professional and personal time and determine the available time.

e. Maintain a running average (sum of the time divided by number of days observed) for each term, by subclass, using all the data collected to that point.

f. When the values of the averages begin to stabilize, the data can be examined and those subclasses with similar times grouped to reduce the data collection effort.

g. Random sampling of the consolidated groups should continue until the averages have stabilized over time so that temporal effects are accounted for.

h. In addition daily figures are required for each subclass indicating the number of physicians assigned and the number actually employed in direct health care each day. This data will be used to adjust the daily figures to other period measures.

4. Availability

The following variables are defined:

hDR_i — the available time per day for one physician of type i

NDR_i — the number of physicians type i assigned

n — the number of days in the model period

mod_i — a model factor to convert daily data to the model period

ADR_i — total available time of physician type i

Availability during the model period is then computed:

$$ADR_i = NDR_i * hDR_i * n * mod_i \qquad (27)$$

This equation asserts that available time (ADR_i) is equal to physician hours available per day (NDR_i * hDR_i) multiplied by the number of days in the model period (n). The factor mod_i is a complicated but extremely useful adjustment factor used to modify the daily data to reflect the true availability of physicians during the model period. This factor is discussed in the next paragraph.

5. <u>The Model Factor</u>

Data collected in accordance with the procedure outlined above yields available time for a physician employed in direct health care on a given day. While observing the operation of Oakland Hospital it was noted that the number of physicians in a given medical service seeing patients varies by day of the week; from week to week during the month; and by month during the year, especially around traditional vacation and holiday periods. Use of an adjustment factor to reflect these fluctuations in manpower utilization during the model period provides flexibility in using a single data bank for a wide range of time periods.

During the course of a particular study it may be desired to investigate a particular day of the week; a particular month; an average day or month; a year; or any other period. The daily data showing the number of physicians employed versus the number assigned provides the information needed to compute the model factor for any such period which is not less than one day in length.

Whatever period is modeled, the model factor is computed as

$$(28) \qquad mod_i = \frac{\Sigma \frac{\text{doctors employed}}{\text{doctors assigned}}}{\#\text{ of sample days}} \quad , \quad \text{where}$$

the summation is over all the sample data points used. For a specific day or month, for example, several data points covering the period would be used for an average. To determine an average day, month or year, data from throughout the period would be used to determine the average availability during the period. Thus when the model factor is multiplied by the maximum availability per day ($NDR_i * hDR_i * n$) the result is an adjusted figure reflecting the fluctuations in manpower during the model period.

B. PERSONNEL CONSTRAINTS

The number of persons employed in a particular subclass determines the availability of that subclass as developed in the previous paragraphs. This determines the overall personnel constraint for the NRMC, namely:

$$(29) \qquad DDR_i \leq ADR_i \quad , \quad \text{for given } i$$

How the total resource availability is distributed to locations and different patient categories is a matter of policy. In general, resources must be allocated to inpatient,

outpatient and dispensary practice. Resources for inpatient care must be further allocated between wards and special facilities. Modeling these allocations is not difficult once the existing or proposed policy is determined. The following illustrates several possibilities in order that the techniques may be understood and applied as required in specific studies.

1. Specific Locations

The allocation policy at each location must be determined. The possible policies at a dispensary serve as an example for any location. There are four cases:

a. No resource time of a particular subclass i is allocated to the dispensary.

b. There are physicians of the subclass i assigned to the dispensary and they only practice there.

c. Physicians of subclass i are allocated from the hospital to the dispensary on some scheduled or demand basis.

d. An allocation scheme combining b and c above is used.

These cases can be formulated as follows, with i and j specified in each case.

Case a: $ADR_{i,j} = 0$

Case b: $ADR_{i,j} = NDR_{i,j} * hDR_i$

Case c: if there is a maximum time allotted

$ADR_{i,j} \leq$ max time allotted

if there is a minimum time allotted

$ADR_{i,j} \geq$ min time allotted

Case d: the equations for this case have two components. The availability of physicians assigned to the dispensary is $NDR_{i,j} * hDR_i$. The increment added by allocation from the hospital depends on whether it is scheduled or provided as demand requires:

scheduled:

$$ADR_{i,j} = NDR_{i,j} * hDR_i + (\text{time allotted})$$

by demand:

$$ADR_{i,j} \geq NDR_{i,j} * hDR_i$$

2. <u>Allocation throughout NRMC</u>

a. Fixed Allocation to Locations

Time is allocated to each required location based on management judgement. Each location availability is an independent constraint and slack time in one location is not allocated to another. In this case:

$$DDR_{i,j} \leq ADR_{i,j} \tag{30}$$

for each j employing physician type i. In this case:

$$ADR_i = \sum_j ADR_{i,j} \tag{31}$$

b. Variable Time Allocation

To model variable time allocations it is necessary to specify the order in which the allocation will be made. The following hypothetical allocation scheme is used for illustration:

first — special facilities
second — wards
third — primary treatment area
fourth — dispensaries

Having specified the order of allocation a sequence of constraints is needed:

$$ADR_{i,j1} = ADR_i \tag{32}$$

where j1 indicates the special facility location. This constraint allocates the maximum available time to the special facility. The unused availability is then further allocated:

$$ADR_{i,j2} = ADR_i - \Delta_m DDR_i \tag{33}$$

where j2 is the ward location and m determines the proper submodel.

$$ADR_{i,j3} = ADR_i - \Delta_m DDR_i - DDR_{i,j2} \tag{34}$$

where j3 is the primary treatment area location code. This equation has allocated to the primary area the unused resource after the demands of the special facility and ward have been met. The remainder is allocated to dispensaries:

$$ADR_{i,j4} = ADR_i - \Delta_m DDR_i - DDR_{i,j2} - DDR_{i,j3} \tag{35}$$

where j4 is the dispensary code. There may be more than one dispensary requiring the resource. This would be modeled in the same manner with additional equations reflecting the policy of allocation to dispensaries.

c. Alternate Policies

Between the two extreme policies outlined above there is room for numerous combinations. The following set of equations illustrate one possibility:

codes:
- j1 — special facility location
- j2 — ward location
- j3 — primary treatment area
- j4 — dispensary
- k1 — a constant
- k2 — another constant
- m — submodel associated with j1

(36) $$ADR_{i,j3} \geq k1$$

(37) $$ADR_{i,j1} + ADR_{i,j2} \leq k2$$

(38) $$ADR_{i,j4} = ADR_i - \Delta_m DDR_i - DDR_{i,j2} - DDR_{i,j3}$$

(39) $$ADR_{i.j3} = ADR_i - \Delta_m DDR_i - DDR_{i,j2} - DDR_{i,j4}$$

The combined effect of these equations is to say that a minimum time, k1, will be employed in the outpatient area (equation (36)); no more than k2 time will be employed for inpatient care (equation (37)); surplus time will be allocated to the dispensary (equation (38)); and if the demand at the dispensary is insufficient, the remaining time will be employed in the outpatient area (equation (39)).

C. CROSS UTILIZATION OF PERSONNEL

Some personnel categories are substitutes for others. Physicians can substitute for residents, registered nurses for licensed nurses, technical personnel for non-technical. Decisions to allocate the existing slack time of one resource for another are common in health facility operations. These substitutions could be incorporated into the model directly using equations similar to those developed in the preceding paragraph. It seems practical not to do so until analysis points out the bottleneck resources. Decisions would then be required on the basis of the operating conditions presented by the model, thus simulating real management decision processes.

To incorporate the allocations directly into the model it is necessary to specify the order substitutions are to occur in. Once these equations are put in the model the allocation process cannot be controlled and important resource information could be lost. For these reasons, cross utilization equations are not formulated for the initial analysis.

D. PATIENT CATEGORY CONSTRAINTS

Limits on the number of patients of a particular category or group of categories which are treated in a period occur due to policy decisions involving the following considerations:

Scheduling of hours for clinics
Limits on voluntary surgery admissions
Meeting minimum accreditation requirements

It is assumed in the initial model that accreditation requirements will be met during the course of normal operations. A list of these requirements should be developed and compared against the model output to verify this. Accreditation requirements are normally stated as some minimum number of a specified procedure to be performed per year. If a hypothetical policy change causes one of these restrictions to be approached, constraint equations can be included in the model in similar form to the other equations illustrated.

1. Inpatient Class Restrictions

For ease of discussion a patient class is defined to be a collection of patient categories for which a restriction applies collectively. A constraint to limit the number of beds assigned for care of an inpatient class is written:

$$(40) \qquad \sum_k DFA_{i,j,k} \leq \sum_k AFA_{i,j,k} \qquad \text{where}$$

the range of k covers the patient categories assigned to the class, i and j are specified as required. In order to determine the factor $\sum_k AFA_{i,j,k}$ it is not necessary to actually fix the limit for each patient category. A single number chosen in accordance with a policy decision suffices for the collective restriction. It is possible that these constraints may include more than one location simultaneously. In this case:

$$(41) \qquad \sum_j \sum_k DFA_{i,j,k} \leq \sum_j \sum_k AFA_{i,j,k} \qquad \text{where}$$

the range of i and k is as before while the range of j is chosen to cover all the required locations. In both cases $AFA_{i,j,k}$ is determined as:

$$AFA_{i,j,k} = (\text{\# beds allowed patient category k}) * (\text{\# days in period})$$

2. Outpatient Class Restrictions

The modeling of outpatient class restrictions is more difficult since in many areas treatment is not reserved solely to physicians. Naval hospitals define 'limited Services' as treatment by paramedic, nursing and medical personnel excluding physicians. In FY72 the following outpatient areas of Oakland Naval Hospital reported limited services: Allergy, Chest Disease, Emergency Room, General Medicine, General Practice, OB/GYN, Opthamology, Pediatrics and Psychology. Thus, the formulation of constraints on outpatient classes varies. The most complicated constraint will be illustrated, the rest being written by dropping inapplicable variables.

The availability of resources at location j for patient class k is determined by:

$$(42) \qquad AFA_{i,j,k} = AINR_{j,k} + AIPM_{j,k} + AIMA_{j,k} + AIDR_{j,k}$$

where

$AIXX_{j,k}$ = the number of personnel authorized to treat patients multiplied by the operating time of the clinic

In order to simplify the model somewhat it is assumed that limited services are homogeneous with respect to which personnel category can perform them. If this is not the case a series of equations of the same form as Equations (30) to (39) may be required. Assuming homogeneity the maximum patient restraint is written:

$$(43) \qquad \sum_k DFA_{i,j,k} \leq \sum_k AFA_{i,j,k} \qquad \text{where}$$

the range of k is specified as required. The following equation is needed to ensure patient categories requiring physician time are not treated as limited services by the model:

$$(44) \qquad \sum_k DIDR_{j,k} \leq \sum_k AIDR_{j,k} \qquad \text{where}$$

the range of k is as above. The subscript j determines the medical service conducting the clinic. The patient categories k are chosen to specify the actual clinic within the medical service (See Section X).

E. MILITARY RESERVE CAPACITY

Military hospitals, in performing their primary mission of medical support to combat forces, must plan on a contingency basis. In addition to normal operations, capacity and capability must be maintained to cope with sudden influxes of combat casualties. This may require maintenance of

unemployed resources. In evaluating the cost and benefit of operating various component facilities of the NRMC this requirement for military reserve capacity must be considered. The amount by which the cost to operate an area exceeds its immediate benefit is, up to the minimum reserve requirement, the cost of that reserve. Any cost above the minimum that does not produce immediate benefits represents lost opportunity cost and should be reallocated.

Military reserve requirements are not formulated in the model but are mentioned here to emphasize their existence.

F. DYNAMIC MODELING CONSTRAINTS

Dynamic modeling is discussed in Section VIII, however, brief mention should be made here of the fact that additional constraints occur when the output of one stage is used as input to the next. The nature of these constraints is to require that some minimum amount of resources be consumed in certain areas. These minimum constraints come about as the result of: 1) patients not treated in the previous stage due to exhaustion of required resources; and 2) normal patient flow through the system. These considerations are dealt with in more detail in Section VIII.

G. BACKLOG FUNCTIONS

Not all constraints need be construed as absolutely binding in the sense that further input is stopped. Once a capacity or equipment availability limit has been reached, there is no recourse but to cease accepting further demands

for the resource. On the other hand, personnel can work overtime and limited backlogs can be allowed to develop in areas such as medical records and laboratory tests.

The excess of demand over availability is measured and accounted for in the variable OXX_{ijk} where XX is any resource variable. For example:

$$OMR_{2,j,k} = (DMR_{2,j,k} - AMR_{2,j,k})^{+} \qquad \text{where}$$

$(\ )^{+}$ indicates $OMR_{2,j,k}$ is either positive (when DMR > AMR) or zero (When DMR $\leq$ AMR).

If a backlog is allowed for a resource then there should be a penalty applied which reduces the benefit calculations by some function of the backlog. Such penalty functions should be developed when the objective function is derived.

VIII. DYNAMIC MODELING

This section develops the additional considerations required in using time as a factor in the model. Time is modeled implicitly by dividing a period into suitable subperiods and using the length of the subperiod as model time. After each computational run through the model, the values of some variables are changed to reflect conditions existing at the beginning of the next run.

A. ADDITIONAL VARIABLES REQUIRED

1. $PCT_{k,m}$ - The Patient Transformation Factor

This factor indicates the percent of patients of category k who become patients of category m. In general, the patient category determines the location of treatment so specific recognition of each area is not required. Data is available to estimate the percentage of clinic patients who become inpatients. Data is not readily available to compute the percentage for the flow of patients through the general practice clinic or the emergency room to outpatient clinics, nor for the transformation of inpatients to outpatients.

B. DYNAMIC CONSTRAINTS

Using the data from a model stage and the transformation factor, minimum initial resource demand in the succeeding stage is computed. First, minimum patient increments are generated for each patient category:

$$\min P_m = \sum_k (P_k * PCT_{k,m})$$

The resource requirements of these increments are calculated as in the following example:

$$\min DDR_{i,j,k} = (\min P_m) * RDR_{i,j,k}$$

Finally, the backlog for each resource is added to create the constraint:

$$DDR_{i,j,k} \geq \min DDR_{i,j,k} + ODR_{i,j,k}$$

This constraint should be considered during decisions on resource reallocation between stages, but it need not be input to the model directly. The following procedure will input the information from the previous stage and still allow the analysis of the impact of patients input in the current stage.

The procedure uses an initial value of backlog function as an input, for example, $ODR'_{i,j,k}$, where:

$$ODR'_{i,j,k} = \min DDR_{i,j,k} + ODR_{i,j,k}$$

ODR' indicates the input value for the current stage, while ODR is the output value from the previous stage. At the beginning of the next computational run the value of demand

for each resource is incremented by the value of the backlog input, for example:

$$DDR_{i,j,k} = ODR'_{i,j,k}$$

$ODR'_{i,j,k}$ is then set to zero so that at the end of the run the correct new backlog can be output. This procedure is not necessary but does provide additional information at each stage.

C. MODELING OVERTIME

In dynamic modeling it may be of interest to study crises situations. Use of the backlog functions could be made to model personnel overtime.

Availability in the model is estimated based on normal working conditions. Crisis operating conditions are characterized by demand overwhelming normal supplies of resources. The greater the overtime requirements, or the more prolonged the crisis, the more resource availability in the near future is affected by the need to refresh overworked personnel.

The use of non-linear functions of backlog, e.g., f(ODR), to decrease resource availability in succeeding stages as a result of current stage crises could be made to simulate the effects of many different emergency situations on system capability.

IX. COST EQUATIONS

Two major concerns of decision-makers are the effects their decisions will have on output and the cost of that output. Of primary importance should be the question of whether or not current resources are efficiently employed and if not what reallocations are necessary to achieve efficiency. Answers concerning the effect of decisions on overall cost require only that accurate estimates of total cost changes be computed. Questions of efficiency require breakdowns of cost by area so that the costs and benefits of each area can be compared. Two formulations of the total cost of the NRMC are presented. The first is suitable for overall cost change analysis and is easier to estimate because by using the present organizational structure and avoiding the need to allocate costs to different operating areas existing data can be used directly. The second formulation is more difficult to develop, estimate and use since it seeks to distribut overhead costs according to work load. The proposed organization presented in the introduction to the model is used for the framework in this development. Each formulation will be useful in different studies so both are presented.

A. GENERAL DISCUSSION

1. The Nature of Costs

The costs of operating the NRMC can be divided into tow general categories — fixed and variable. Fixed costs

are considered to be those that do not vary within some range of workload of interest in the study; variable costs change with changes in workload. The determination of which costs are fixed and which variable depends to a great degree on the purpose of the study. It is often convenient to consider as fixed many costs whose variation is complex yet relatively stable or insignificant to the total cost. It is also necessary in complex studies such as the present one to arbitrarily define some costs as fixed while investigating others until, after several stages of analysis, the significant variable costs have been isolated. Fixed cost assumptions for the initial model will be listed below.

2. Modeling Costs

There are two general procedures for developing cost equations for models. The first is statistical analysis of historical data to determine how cost varies with workload. A simple linear example is shown in figure 1. Assuming the

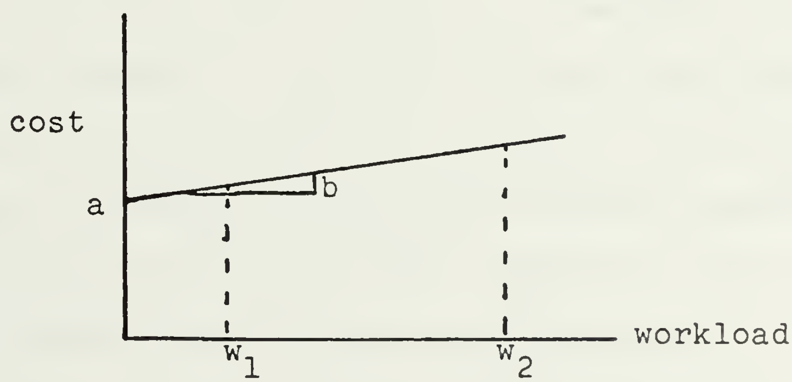

figure 1

workload range of interest to be represented by w_1-w_2, the cost to operate at w_1 to be a and the cost per unit of

additional workload to be b then a would be the fixed cost and b * workload the variable cost. The cost equation would be written: cost = a + b * workload. This procedure has the advantage of not requiring a detailed study of how the costs were generated and is useful for modeling as long as the model workload range is close to the data used to estimate the equation.

The second method of modeling costs is to identify the individual factors generating the cost, determine the cost per unit of each factor and the number of units required as a function of workload. The individual factors with their unit cost coefficients are then combined into a cost equation. This method has the advantage of showing how costs vary with different mixes of factors employed. Both methods are needed in the NRMC model.

3. Cost Coefficients

For each resource specified in the model a coefficient appears in the cost equations to indicate the cost per unit of that resource. A question arises concerning what data should be used to estimate values for the coefficients. In the case of civilian personnel this should generally be a weighted average of the pay grades employed in the resource, using the combined cost of salary and benefits.

In the case of military personnel the problem is more complex. There are several sources of data giving the cost of military personnel. One measure uses only salary and benefits; another adds individual training costs; a third

includes retirement costs. Each measure uses different aggregation schemes to generate average values. In addition to the problem of which cost to use, there is an added problem caused by the fluctuation in manning levels and pay grade mix over relatively short periods of time. For the initial analysis it is proposed that the weighted average cost of personnel allowed by the manning document [Ref. 7] be used. While the cost data to be used will vary with the decision-maker using the model it seems reasonable that for the NRMC-level analysis the actual salary plus allowances be used since that is the cost to the system of employing those resources.

B. TOTAL COST FORMULATED WITH PRESENT ORGANIZATION

The easiest total cost equation to estimate is one based on the present organization that does not require a detailed breakdown, by area, of cost. This is most simply accomplished by recombining the model locations into the medical and administrative divisions to which they belong, adjusting certain cost data and using statistical estimation to derive the cost equation for each service. The details of this procedure are described below.

1. Constant Cost Areas

The following areas are considered to have constant cost, C_i, for the initial analysis:

i = 1 - office of commanding officer

2 - data processing division

3 - medical technician school

4 - preventive medicine unit

5 - public works division

6 - security division

7 - special services division

8 - military personnel division

9 - dental service

For each area the current budget allocation can be used as an estimate for C_i.

2. Fixed and Variable Cost Areas

For each area listed in this category it appears that complex cost variation with patient load exists. Specific components of some areas, such as food service and housekeeping, may require direct incorporation into the model for detailed analysis after the initial study is complete. For each area statistical analysis of historical data is required to estimate the cost equations $F_i = a_i + b_i * (\sum_k P_k)$ where a_i is the fixed cost of area i and $\sum_k P_k$ is the total patient load.

i = 1 - fiscal and supply division

2 - food service division

3 - operating services division

4 - patient affairs division

5 - pharmacy service

3. Medical Services

For each medical service, the historical cost data must be adjusted by subtracting the costs of personnel resources which are directly included in the model. Care must

be exercised in this adjustment for Hospital Corps personnel (and other similar categories) since only those engaged in specific duties are included in the model. Those performing general administrative duties are not part of the model resources and their cost is included in the individual service equations. These equations, designated $G_i = c_i + d_i * (P_k)$, are then statistically estimated using the adjusted historical data.

i = 1 - anesthesiology service
2 - dermatology service (3,14)**
3 - medical service (4,15)
4 - neuropsychiatry service (5,16)
5 - neurology service (13,24)
6 - nursing service
7 - OB/GYN service (6,17)
8 - opthamology service (7,18)
9 - orthopedic service (8,19)
10 - otolaryngology (9,20)
11 - outpatient service (1,2)
12 - pediatric service (10,21,25)
13 - surgical service (11,22)
14 - urology service (12,23)
15 - radiology service
16 - laboratory service

** numbers in parenthesis indicate location codes j included in the service

In addition the following model areas should be included in the indicated medical service:

Medical Service:

medical intensive care
cardiac care unit

Otolaryngology Service

audio-visual therapy

Orthopedic Service

prosthetics laboratory
physical therapy
occupational therapy

Surgical Service

operating room
surgical intensive care

Radiology Service

radiation therapy

OB/GYN Service

delivery room
labor room

4. Dispensaries

The cost of each dispensary is computed separately using the same techniques explained above. The nine dispensary cost equations are of the form $D_i = e_i + f_i * (\sum_k P_k^i)$, $i = 1\text{-}9$, where P_k^i is a notation convention to indicate that the patient load at the individual dispensary is to be used.

5. Resource Costs

The number of personnel employed in each resource category multiplied by the unit cost coefficient generates the resource cost. Resource categories can be aggregated to the main variable level, e.g., NDR, if the variance in the resultant cost coefficient, e.g., $DR, is not too great;

or costing can be done by subclass, e.g. NDR_1 and $\$DR_1$. In the following equations all sources of employment are listed, which may add to the resources accounted for by the resource vector variable. Care must be exercised during initial use of the model to avoid double counting. The personnel resource cost equations are:

(45) $BDR = \$DR\ (NDR + NST_{10} + NPL_1 + NPR_1)$

(46) $BDS = \$DS\ (NDS + NPL_5 + NPR_2)$

(47) $BNR = \$NR\ (NNR + NST_9 + NST_{11})$

(48) $BPM = \$PM * NPM$

(49) $BMR_2 = \$MR_2\ (NMR_2 + NPL_7 + NPR_5 + NPT_3 + NOT_3 + NAT_3)$

(50) $BMA = \$MA\ (NMA + NPL_6 + NPR_3 + NPR_4 + NPT_2 + NOT_2 + NAT_3)$

(51) $BST = \$ST_7 * NST_7 + \$ST_8 * NST_8$

(52) $BPL = \sum_m (NPL_m * \$PL_m)\ ,\quad m=2,3,4$

(53) $BPT = \$PT_1 * NPT_1$

(54) $BOT = \$OT_1 * NOT_1$

(55) $BAT = \$AT_1 * NAT_1$

6. <u>The Total Cost Equation</u>

The total cost equation for the NRMC is then written:

$$\text{(56)} \quad \text{TOTAL COST} = \sum_{i=1}^{9} C_i + \sum_{i=1}^{5} F_i + \sum_{i=1}^{16} G_i + \sum_{i=1}^{9} D_i + BDR$$

$$+ BDS + BNR + BPM + BMR_2 + BMA$$

$$+ BST + BPL + BPT + BOT + BAT$$

The same equation can be written in a different form which segregates the types of cost together. This equation is written:

$$\text{(57)} \quad \text{TOTAL COST} = \text{FIXED COST} + \text{VARIABLE COST}$$

$$+ \text{RESOURCE COST}$$

where:

$$\text{(58)} \quad \text{FIXED COST} = \sum_{i=1}^{9} C_i + \sum_{i=1}^{5} a_i + \sum_{i=1}^{16} c_i + \sum_{i=1}^{9} e_i$$

$$\text{(59)} \quad \text{VARIABLE COST} = [(\sum_{k} P_k) * (\sum_{i=1}^{5} b_i + \sum_{i=1}^{16} d_i)]$$

$$+ \sum_{i=1}^{9} [(P_k^i) * f_i]$$

$$\text{(60)} \quad \text{RESOURCE COST} = BDR + BDS + BNR + BPM + BMR_2 + BMA$$

$$+ BST + BPL + BPT + BOT + BAT$$

C. PRELIMINARY DISCUSSION OF AREA COSTING

The formulation developed in this and the following section is independent of the preceding one. Equations from the two formulations cannot be mixed together because, while the notation is similar, the variables denoted are defined differently.

The general technique in this formulation is to aggregate identifiable costs by area and to allocate the remaining cost by workload. While it would be desirable to estimate the total fixed and variable costs of each area individually, the data presently available is insufficiently detailed.

1. Cost Coefficients

The cost coefficients in this set of cost equations must be developed by subclass, using the same cost data previously described. The physician variable is used for illustration of the derivation required for each personnel resource variable. Using whatever cost data is required by the analysis and the estimates of availability defined in section VII.a.4 the cost coefficient for a physician class i is computed as:

$$\$DR_i = \frac{\text{monthly cost per physician type i}}{30 * hDR_i}$$

$\$DR_i$ can be considered as the cost per unit (hour or minute) of available time of physician type i. This definition has an advantage in that it distributes cost by available time only and thus provides a variable which can be used to

analyze the effect of prescribing more or less professional time on the cost-benefit ratios associated with the resource. In this manner the importance of professional time is recognized without direct incorporation into the model.

2. Allocation of Resource Cost to Areas

The availability of a resource subclass is equal to the sum of its availabilities to all locations. Having defined the cost coefficient in terms of availability units allows an allocation computation for area j as: cost to area j for resource $DR_i = \$DR_i * ADR_{ij}$. In this case:

$$BDR_i = \$DR_i * ADR_i = \sum_j \$DR_i * ADR_{ij} \text{ , } j=1\text{-}34$$

There is one situation in the model where a deviation from this procedure is necessary. If availability is assigned on a demand basis as illustrated in equations (32) through (39) then DDR_{ij} must be substituted for ADR_{ij} in those areas where demand is the criteria for manning.

3. Allocation of Fixed and Variable Cost

Lacking data to derive the independent area cost equations requires distribution of the service costs as defined in the first formulation in such a manner as to approximately reflect the real source of these costs. As a first approximation, cost for a service computed in the equations estimated from adjusted historical data is distributed in accordance with percentages reflecting the proportion of total demand generated in each area funded by that service.

A better approximation could be achieved by determining, for those personnel not specified in the model, the area of their employment and how employment in that area varies with patient load. The service cost data could then be adjusted further by subtracting all personnel costs, estimating new equations and distributing this reduced cost by demand. Provision is made in the cost equations below for these revised estimates.

D. TOTAL COST FORMULATED WITH PROPOSED ORGANIZATION

The methodology of this formulation can be applied to any alternate organization hypothesized.

1. Individual Area Cost Equations

In the following list of equations C indicates a constant cost; F indicates an equation of the form $a_i + b_i * L$ which pertains to a medical or administrative department; f indicates an equation of the form $a_i + b_i * L$ for an individual area. L denotes the total patient load for convenience.

F_1 - anesthesiology service

F_2 - dermatology service

F_3 - medical service

F_4 - neuropsychiatric service

F_5 - neurosurgical service

F_6 - nursing service

F_7 - OB/GYN service

F_8 - opthamology service

F_9 - orthopedic service

F_{10} - otolaryngology service

F_{11} - outpatient service

F_{12} - pediatric service

F_{13} - surgical service

F_{14} - urology service

F_{15} - laboratory service

F_{16} - pharmacy service

F_{17} - radiology service

F_{18} - fiscal and supply division

F_{19} - food service division

F_{20} - operating services division

F_{21} - central administration

F_{22} - patient affairs division

F_{23} - public works

F_{24} - security division

F_{25} - special services division

C_{26} - clinical investigation center

F_{27} - data processing division

C_{28} - preventive medicine unit

f_m - primary treatment areas

m = 29 - allergy
30 - cardiology
31 - dermatology
32 - otolaryngology
33 - emergency room
34 - general practice
35 - internal medicine
36 - neuropsychiatry
37 - neurosurgery
38 - OB/GYN
39 - opthamology
40 - orthopedics
41 - pediatrics

42 - surgery
43 - urology

f_m - secondary treatment areas

m = 44 - cardiology
45 - dermatology
46 - otolaryngology
47 - internal medicine
48 - neuropsychiatry
49 - neurosurgery
50 - OB/GYN
51 - opthamology
52 - orthopedics
53 - pediatrics
54 - surgery
55 - urology
56 - cardiac care unit
57 - delivery room
58 - labor room
59 - medical intensive care unit
60 - operating suite
61 - nursery
62 - surgical intensive care

f_m - treatment support areas

m = 63 - aural-speech therapy
64 - drug rehabilitation
65 - occupational therapy
66 - physical therapy
67 - radiation therapy

f_m - diagnostic support

m = 68 - EEG
69 - EKG
70 - nuclear medicine

f_{71} - central sterilizer

c_{72} - chaplains

c_{73} - medical library

c_{74} - medical repair

c_{75} - nursing administration

f_{76} - prosthetics laboratory

2. Area Costs

The initial model does not directly include all the areas listed in the proposed organization. Where this is the case, organization areas have been grouped into the modeled areas for cost allocation. The cost equations in this section represent the costs of operating an area, not the costs imposed on other areas as a result of that area's operations. The latter costs are formulated in a later paragraph.

All equations assume fixed allocation restraints are used in the model. The equations F_m have two potential interpretations. If individual area equations f_m are available then F_m represents the department administrative expense after area costs have been subtracted. If individual estimates are not available then the appropriate f_m are deleted and F_m represents overall fixed and variable costs for the department.

Due to the repetitive nature of the calculations in the equations details are suppressed after sufficient examples have been presented.

Primary Treatment

General Practice Clinic (includes miltary sick call)

(61) $$BIKFA_1 = f_{34} + \$DR_2 * ADR_{2,1} + \$PM_1 * APM_{1,1} + \$MR_2 * AMR_{2,1} + \$MA_1 * AMA_{1,1} + \sum_{i=1}^{8} (\$DS_i * ADS_{i,1}) + \sum_{i=1}^{4} (\$NR_i * ANR_{i,1})$$

Emergency Room

(62) $$BIKFA_2 = f_{33} + \$PM_1 * APM_{1,2} + \$MR_2 * AMR_{2,2} + \$MA_1 * AMA_{1,2} + \sum_{i=1}^{14} (\$DR_i * ADR_{i,2}) + \sum_{i=1}^{4} (\$NR_i * ANR_{i,2}) + \sum_{i=1}^{8} (\$DS_i * ADS_{i,2})$$

NOTE: fixed and variable cost for the general practice and emergency room are included in outpatient administration.

Dermatology (includes allergy)

(63) $$BIKFA_4 = f_{29} + f_{31} + \frac{DIKFA_3}{DIKFA_3 + DIKFA_{14}} * F_2 + \$DR_1 * ADR_{1,3} + \$PM_1 * APM_{1,3} + \$MA_1 * AMA_{1,3} + \$MR_2 * AMR_{2,3} + (\$NR_i * ANR_{i,3})$$

NOTE: the coefficient of F_2 computes the percent of dermatology workload generated in the primary treatment area. The remaining allocation coefficients are calculated in the same manner and will be designated '%' except where differences are written out explicitly. Since personnel costs are computed in a similar manner as the

previous three illustrations they will be designated 'Personnel Cost' in the remaining equations for convenience.

Medical Service (includes cardiology and internal medicine)

(64) $$BIKFA_4 = \% F_3 + f_{30} + f_{35} + \text{personnel cost}$$

$$\% = \frac{DIKFA_4}{DIKFA_4 + DIKFA_{15} + DSF_1}$$

Neuropsychiatry

(65) $$BIKFA_5 = \% F_4 + f_{36} + \text{personnel cost}$$

Obstetrics and Gynecology

(66) $$BIKFA_6 = \% F_7 + f_{38} + \text{personnel cost}$$

$$\% = \frac{DIKFA_6}{BIKFA_6 + BIKFA_{17} + DSF_4 + DSF_5}$$

Opthamology

(67) $$BIKFA_7 = \% F_8 + f_{39} + \text{personnel cost}$$

Orthopedics

(68) $$BIKFA_8 = \% \; F_9 + f_{40} + \text{personnel cost}$$

$$\% = \frac{DIKFA_8}{DIKFA_8 + DIKFA_{19} + DTH_2 + DTH_3}$$

Otolaryngology

(69) $$BIKFA_9 = \% \; F_{10} + f_{32} + \text{personnel cost}$$

$$\% = \frac{DIKFA_9}{DIKFA_9 + DIKFA_{20} + DTH_1}$$

Pediatrics

(70) $$BIKFA_{10} = \% \; F_{12} + f_{41} + \text{personnel cost}$$

Surgical

(71) $$BIKFA_{11} = \% \; F_{13} + f_{42} + \text{personnel cost} + \$ST_i * AST_{i,11}$$

$$\% = \frac{DIKFA_{11}}{DIKFA_{11} + DIKFA_{20} + DOR_i + DSF_2}$$

Urology

(72) $$BIKFA_{12} = \% \; F_{14} + f_{43} + \text{personnel cost}$$

Neurology

(73) $BIKFA_{13} = \% F_5 + f_{37} +$ personnel cost

Secondary Treatment

The secondary treatment equations $BIKFA_j$, j=14-25 are written in the same manner as the primary treatment equations.

Treatment Support

The cost for each of the three therapy facilities treated as submodels is computed as:

(74) $$BTH_1 = \% F_{10} + f_{63} + \sum_{i=1}^{3} (\$AT_i * AAT_i)$$

(75) $$BTH_2 = \% F_9 + f_{66} + \sum_{i=1}^{3} (\$PT_i * APT_i)$$

(76) $$BTH_3 = \% F_9 + f_{65} + \sum_{i=1}^{3} (\$OT_i * AOT_i)$$

The remaining treatment support areas are modeled only as cost equations listed in paragraph 1 above.

Diagnostic Support

The two diagnostic support areas incorporated in submodels are:

Laboratory

(77) $$BLB = F_{15} + \sum_{i} \sum_{m} (\$PL_m * APL_{i,m})$$

Radiology

$$\text{(78)} \qquad BXR = F_{17} + \sum_{i}\sum_{m} (\$PR_{i,m} * AIPR_m)$$

All other required cost equations are of the form f_m and F_m and are listed above.

3. The Total Cost Equation for Hospital

$$\text{(79)} \qquad \text{TOTAL COST} = \underbrace{\sum_{i=1}^{13} BIKFA_i}_{(1)} + \underbrace{\sum_{i=14}^{25} BIKFA_i}_{(2)} + \underbrace{(F_{11} + F_{22})}_{(3)}$$

$$+ \underbrace{\left(\sum_{i=1}^{3} BTH_i + F_{16} + f_{64} + f_{67} + f_{76}\right)}_{(4)}$$

$$+ \underbrace{(BLB + BXR + f_{68} + f_{69} + f_{70})}_{(5)}$$

$$+ \underbrace{\left(F_{19} + f_{71} + \sum_{i=72}^{75} C_i\right)}_{(6)} + \underbrace{\left(\sum_{i=23}^{25} F_i\right)}_{(7)}$$

$$+ \underbrace{(F_{18} + F_{20} + F_{21} + F_{27} + C_{26} + C_{28})}_{(8)}$$

where: (1) = primary treatment cost
(2) = secondary treatment cost
(3) = medical administration cost
(4) = treatment support cost
(5) = diagnostic support cost
(6) = non-treatment support cost
(7) = base support cost
(8) = general support cost

The increment for each area generated in the dispensaries is calculated in the same manner and must be added to complete the NRMC total cost equation.

E. RESOURCE COST PER PATIENT CATEGORY

The cost per patient category of the resources used is developed from the model by summing all the variables over i and j for the particular patient category k. In the case of support facilities there are two methods of attributing cost to the patient category. The first is to enter the submodel and sum each submodel variable in the same manner as all other variables, treating the total as the resource cost for the patient category. The second method, which is used in the formulation given below, distributes the entire cost of the support areas to patient categories.

Grouping patient categories together to form a class which represents the patient load at a particular location has the effect of generating the portion of total system cost attributable to the operation of that location. In that case the overhead costs of the location in question should be added in for completeness. Since the cost of

interest in most studies is the variable cost and how cost changes with increases in a patient category load, either formulation will give approximately the same information because incremental costs ignore fixed portions of system cost.

The equation for a patient category k is:

(80) PATIENT COST =

$$\$DR_i * AJDR_{i,k} + \$DS_i * AJDS_{i,k} + \$NR_i * AJNR_{i,k}$$

$$+ \$PM_1 * AJPM_{1,k} + \$MR_2 * AJMR_{2,k} + \$MA_1 * AJMA_{1,k}$$

$$+ \frac{KIJLB_k}{DLB} * BLB + \frac{DIJXR_k}{DXR} * BXR + \frac{DIJPH_k}{DPH} * BPH$$

$$+ \frac{DIJOR_k}{DOR} * BOR + \frac{DIJST_k}{DST} * BST + \frac{DIJTH_k}{DTH} * BTH$$

X. INPUTS TO A SPECIFIC ANALYSIS

The resource variable accounting for medical record processing time was included to illustrate the potential of the model for providing cost and benefit inputs for analysis of specific problem areas in a health facility. Without explicit definition of benefit calculations the analysis cannot be illustrated completely. This section develops the equations needed to extract what information has already been formulated.

A. PHYSICIAN TIME

The physician time recorded in $RMR_{1,j,k}$ represents that portion of the physician treatment time for a patient of category k in location j which is consumed in creating (writing or dictating) a medical record entry and in reviewing the finished product prior to signature. This time is partially a function of the medical record technology employed. Thus the analysis of the cost/benefit implications of a new technology requires an estimated adjustment to $RMR_{1,j,k}$ to reflect the time-saving expected.

The quantity $DIDR_{j,k}$ represents the physician time required in location j by P_k patients of category k; the quantity $AIDR_{j,k}$, the available time; and the quantity $DMR_{1,j,k}$ the increment of time devoted to medical records. A reduction of $RMR_{1,j,k}$ to $RMR'_{1,j,k}$ creates a new increment of available time:

$$AIDR_{j,k} = (DMR_{1,j,k} - DMR'_{1,j,k})$$

Neglecting small overlaps in the times represented availability is equal to:

$$\Delta AIDR_{j,k} = DIDR_{j,k} + DMR_{1,j,k}$$

Therefore, the added increment of availability allows an increase, ΔP_k, in patients of category k, computed as:

$$P_k = \frac{\Delta AIDR_{j,k}}{DIDR_{j,k}}$$

The cost of physician time represented by $DMR_{1,j,k}$ is computed as a percent of the physician cost in area j for patient category k:

$$\frac{DMR_{1,j,k}}{DIDR_{j,k}} * BIDR_{j,k}$$

B. PROCESSOR TIME

The variable $RMR_{2,j,k}$ represents the preparation time required for the same records discussed above. A change in technology changes $RMR_{2,j,k}$ to $RMR'_{2,j,k}$. The resultant change in availability is:

$$\Delta AMR_{2,j,k} = DMR_{2,j,k} - DMR'_{2,j,k}$$

The incremental number of records which can be processed is:

$$\frac{\Delta AMR_{2,j,k}}{RMR'_{2,j,k}}$$

The cost increment of processing due to personnel time is:

$$\$MR_2\ (RMR_{2,j,k} - RMR'_{2,j,k})$$

C. CONSIDERATIONS

Procurement cost, operation and maintenance costs and old equipment salvage cost are not included directly in the model when considering a technological change. These amounts affect only the cost side of the cost/benefit analysis and can be added in separately.

These variables are formulated by patient category rather than in the aggregate so that benefit calculations of an increase in some or all patient categories can be calculated. Benefit computations are normally done by patient category. While not the only criteria in a complex decision, the availability of information relating cost and benefit changes to a proposed technological change is important to management.

X. PATIENT CATEGORIES

This section presents hospital data and other considerations important in defining patient categories suitable for use in the model. While a patient categorization scheme is outlined, the detailed analysis required for the final list is beyond the scope of this paper.

A. GENERAL CONSIDERATIONS

One of the traditional categorization schemes used in previous models of health facilities groups patient inputs by homogeneity of resources demanded. Such schemes are useful when one objective of the analyst is to minimize the number of categories in order for the model to reside, in its entirety, in a computer. Unfortunately, compactness also limits the flexibility of such models for detailed analyses such as contemplated in the present study. By programming all the necessary computations, properly formatting the output and using the patient load vector and individual resource vectors as independent inputs, there is no need to limit the number of patient categories defined. It is not of great importance for the present purpose that this procedure does not allow application of mathematical programming techniques in a single run of the data.

It is important for the model as formulated that patient categories be relatively homogeneous with respect to medical service providing primary care. It is desirable that

inpatients and outpatients be independent categories to enable separate analysis of the demands placed by each on the various components of the system. It is also desirable that patient categories be made up of diseases or symptoms requiring similar treatment procedures in order to reduce the variance of parameter estimates. Categories should not be so fine, however, that only minute percentages of workload are represented (unless there is only one category for a particular service).

However defined, the parameter estimates for each category should be the weighted average of estimates for each procedure included in the definition. Care should be exercised to record the precise weighting scheme for each category so that sensitivity analysis by disease can be done if desired. A record of the following form would be most useful:

$$\text{CATEGORY ESTIMATE} = \%_1\text{Estimate A} + \%_2\text{Estimate B} + \%_3\text{Estimate C}$$

B. PATIENT DATA — OAKLAND NAVAL HOSPITAL

The initial step in defining patient categories is to determine how the hospital workload is distributed. Included in this procedure is establishing what the workload is. The data recorded on the Medical Service Reports [Ref. 8] for Calendar Year 1972 along with a data summary for 23376 inpatients treated in Fiscal Year 1973 was used in an analysis of workload distribution.

The following independent categories reported on the Medical Service Report are taken to comprise the workload: Outpatient visits, inpatient visits, limited services, immunizations and physical examinations. The dental department has been disregarded here, as throughout the model, it being considered an independent organization coincidentally located in the hospital building. Included in the list of inpatient visits are physical therapy and occupational therapy visits. It seemed intuitive that these were visits by people included in other inpatient categories and when these visits were subtracted from the total, as shown in Table 11 below, the total inpatient count corresponded closely with the number of inpatient records, allowing for the time difference in the record period. The same consideration led to deleting all anesthesiology visits from the workload of the hospital for analytic purposes. The total workload for the year was then calculated as shown in Table 11. The distribution of the workload over component categories is shown in Table 12.

The distribution of patients throughout the hospital in 1972 is shown in tables 13, 14, 15, and 16. Table 13 provides the percentage distribution of workload by the categories listed on the Medical Service Report. Although the distribution of workload is not to be equated with the distribution of resource demand under the present definitions, it is interesting to note that three areas – allergy, general practice and opthamology – account for 46.85% of the total

TABLE 11

WORKLOAD CALCULATION

Total outpatients listed	299011
Total inpatients listed	56494
Subtotal	355505
Less physical therapy inpt.	(12855)
	342650
Less occup. therapy inpt.	(6133)
	336517
Total limited services	139182
Total immunizations	30138
Total physicals	4849
	510686
Less anesthesiology	(13915)
TOTAL WORKLOAD	496771

TABLE 12

DISTRIBUTION OF WORKLOAD

	Number	%
Adjusted outpatients	298170	60.02
Adjusted inpatients	24432	4.92
Limited services	139182	28.02
Immunizations	30138	6.06
physicals	4849	0.98
TOTAL WORKLOAD	496771	

workload. Table 14 presents the distribution of workload within each area as a percentage of that area and the distribution by area of all outpatient visits, all inpatient visits and all limited services. Six areas account for 60.11% of outpatient visits; four areas for 67.27% of inpatient visits; and two areas for 88.5% of limited services. Patient categories in these areas should be carefully

formulated to ensure proper analysis of the resource demand generated. As a general principle it is better to define too many categories initially and have to aggregate them, rather than disaggregating a few since a small number of categories with broad definition may conceal important interactions. Table 15 is provided to illustrate the original numbers used in the percentage calculations. Table 16 lists the support services and the number of services performed by each. The '# per pat.' column contains the number of services for each area per outpatient or inpatient found by dividing total area service by the appropriate number from table 12. (Tables 13, 14, 15, and 16 are located at the end of this section for convenience.)

C. SUMMARY OF FY73 INPATIENT ACTIVITY

A data bank of 23376 records for the inpatients treated in FY73 was provided by Oakland Naval Hospital for use in the overall project. This data was reviewed to determine the distribution of patients by medical and surgical categories using the International Classification of Diseases (ICDA) codes listed in Ref. 10 and recorded for each patient in the data bank.

The result of this review for the surgical codes is presented in table 17 by general groups of ICDA surgical codes. The actual number in each group is given for perspective and the percentage distribution in each area of the total surgical patients reported is computed. The number reported is the number of times the code appears, not

the number of procedures performed (which is also included in the data bank). The percentage of inpatient figures given in the table is the proportion of the 23376 records, not the figure in table 12. Of the 23376 inpatients recorded, 10010 or 42.8% were subject to surgical procedures. The analysis for patient categorization should include determining whether or not certain medical ICDA codes are highly correlated with specific surgical codes since this information would be useful in formulating homogenous categories. The relative concentration of patients in individual codes is indicated in the following list showing the percent of patients covered by various numbers of codes out of the 110 possible:

# OF CODES	% OF SURGERIES	% OF INPATIENTS
5	30.64	13.12
10	46.01	19.70
15	56.75	24.28
20	65.61	28.06
25	72.27	30.91

The result of the review for medical codes is given along with the list of patient categories proposed. The actual number is given for subgroups within the major headings of the ICDA codes which account for 100 or more patients. The number is also given for individual codes accounting for large numbers of patients within a subgroup. The percentage of inpatients represented by each heading is indicated with the heading. The concentration of patients in codes is indicated below. There are 1100 potential general codes.

# OF CODES	% OF INPATIENTS
5	11.68
10	17.99
20	27.20
25	30.36
35	36.13
50	43.10
75	52.00

D. AGE AND SEX CONSIDERATIONS

A preliminary analysis of the patient data to determine broad variations in length of stay for inpatients revealed interesting results when the data was broken into age, sex and patient status groups. These results are outlined here to indicate the necessity for detailed analysis prior to aggregating estimates of resource demand. Some medical codes have relatively consistent length of stay figures, while in others there is wide variance. In almost all cases the figure for military personnel appears significantly different from other categories. Table 18 presents the data for six medical codes selected to show the various results encountered.

Medical code 650 shows consistency between age groups and is an example of a homogeneous category. Code 626, consisting almost entirely of civilian females, shows variation in length of stay by age. For a category of this type a weighted average should be sufficient for a well-defined category, sensitivity analysis on varying the weightings being used to investigate hypothesized changes in the

numbers of one or more age groups. Code 401 shows complex variation, each grouping having a different length of stay.

Two general observations emerge from considering the data in the examples. The first is that there is generally a difference in length of stay between males and females, even disregarding the longer length of stay for military males. Where males and females are both important in a category either weighted averages can be used or two separate patient categories defined. The decision should be based on the similarity in resource demand, and the likelihood that the mix might change. The second observation is that there are pronounced differences in the length of stay for military personnel over that for civilians. This was noted in every medical code for which enough patients had been treated from both categories to feel the average might be representative. For military personnel, the length of stay does <u>not</u> include time they were assigned to the hospital but were on convalescent leave. The data was adjusted for these days which were recorded in the data bank.

It is not surprising that length of stay for military personnel should be longer. A civilian well enough to walk and provide basic self-care can be assigned to the outpatient department for follow-up treatment while the patient is recuperating at home. Military personnel are expected to be ready to perform duties on return to his command. Therefore the length of stay for military includes recuperation time

and it may also include additional time awaiting transfer that was not spent on leave. Evidence is not available to determine the existence of this latter quantity however it should not be dismissed without investigation since any inaccuracy in the military length of stay seriously distorts the overall average for particular medical codes. In lieu of a complete analysis, <u>it seems reasonable for the initial analysis to use the civilian length of stay as the demand on medical resources and to treat the difference between the civilian and military length of stay as a demand on military resources</u>. The total cost of operating the NRMC would then consist of medical cost and military convenience cost. Once a complete investigation has been completed, a weighted average length of stay per patient category can be computed.

Patients seen for the first time in an outpatient clinic often require more time than those returning for follow-on treatment. Either separate categories can be defined and the patient transformation factor used or weightings can be used to model the appropriate patient mix. The decision in part should be based on the policy of the clinic concerned. Some have special hours for first visits, others take them as they come.

The first few days of treating inpatients generally consume much greater amounts of resource than the latter stages of recuperation. The essential difference in these two stages is the demand placed on diagnostic and treatment support facilities. In static analysis these differences

are unimportant since all demands are averaged together. For dynamic studies it may be beneficial to define separate categories for those cases where there is a pronounced change in resource demand and the length of the recuperative period is significant.

None of these considerations have been taken into account in proposing the patient categories below. This list can be considered as the minimum categories for initial analysis and is meant to provide a starting point for the detailed analysis required for final formulation. It should be remembered that the patient categories input to the model need not be those of interest in the output as long as they are capable of proper aggregation in the model computations.

LIST OF PATIENT CATEGORIES**

OUTPATIENT CATEGORIES

k	CLINIC	HOURS
1	Allergy	27
2	Cardiology.	6
3	Electrocardiogram	30
4	Pulmonary Function.	37½
5	Pulmonary Tests	37½
6	Dermatology	17½
7	ACNE.	2
8	Ear-Nose-Throat	15
9	Audiology and Speech Therapy.	40
10	General Practice.	96
11	Internal Medicine	16½
12	Hematology.	5
13	Endocrinology	1½
14	Diabetic.	1½
15	Gastroenterology.	7
16	Rheumatology.	3
17	Tumor (medicine).	1
18	Chest (medicine).	22
19	Nephrology.	4
20	Electroencephalograph	37½
21	Neurosurgery.	15
22	Neuropsychiatry	20+
23	General Surgery	6+
24	Proctology.	1
25	Plastic Surgery	4
26	Vascular Surgery.	2
27	Thoracic Surgery (Bronchoscopy)	4
28	Tumor (surgery)	3+
29	OB/GYN-Prenatal (new)	0
30	OB/GYN-Prenatal (return).	33½
31	OB/GYN-Complicated Pregnancy.	1
32	OB/GYN-Postpartun	2½
33	Family Planning	2½
34	Gynecology.	23
35	Dysplasia	2
36	Tumor (GYN)	1½
37	PAP Clinic.	2½
38	Opthamology	18½
39	Optometry	25
40	Orthopedic.	8
41	Orthopedic (pediatrics)	2
42	Pediatrics.	16
43	Well Baby	2¼
44	Urology	2
45	Cystoscopies.	16
46	IVP	9
47	VCU	6
48	Neurology	12½

** Explanation at end of table

INPATIENT CATEGORIES

k			
	000-136 INFECTIVE AND PARASITIC DISEASE - 3.1 %		
49	000-009	Intestinal Infections - - - -	147
50	050-079	Viral Diseases - - - - - - - - - -	216
		Remainder - - - - - - - - - - - -	297
	140-239 NEOPLASMS - 5.7 %		
52	170-174	Bone, Skin and Breast - - - -	98
53	180-189	Genitourinary Organs - - - - - -	137
54	190-199	Other Malignant Neoplasms - -	168
55	210-228	Benign Neoplasms - - - - - - - - - 218-Uterine Fibroma (124)	469
51		Remainder - - - - - - - - - - - -	357
	240-279 ENDOCRINE AND METABOLIC DISEASE - 3.1 %		
57	250-258	Endocrine Glands - - - - - - - - - 250-Diabetes (281)	375
58	270-279	Metabolic - - - - - - - - - - - - 272-Lipid Metabolism (98)	210
59		Remainder - - - - - - - - - - - -	92
	280-289 BLOOD DISEASE - 1.8 %		
60		Remainder - - - - - - - - - - - -	380
	290-315 MENTAL DISORDERS - 6.5 %		
61	290-299	Psychoses - - - - - - - - - - - - 295-Schizophrenia (114)	178
62	300-309	Non-Psychotic Disorders - - - 300-Neuroses (151) 303-Personality Disorder (509) 307-Transient Disturbance (197)	1222
63		Remainder - - - - - - - - - - - -	8
	320-389 NERVOUS SYSTEM AND SENSE ORGANS - 5.2 %		
64	340-349	Central Nervous System - - - -	109
65	350-359	Nerves, Peripheral Ganglia - -	128
66	370-379	Conditions of Eye - - - - - - - 373-Strabismus (156)	442
67	380-389	Disease of the Ear - - - - - - - - 381-Otitis Media (171)	355
68		Remainder - - - - - - - - - - - -	84
	390-458 CIRCULATORY SYSTEM DISEASE - 8.9 %		
69	400-404	Hypertension - - - - - - - - - - -	346
70	410-414	Ischemic Heart Disease - - - -	563
71	420-429	Other Heart Disease - - - - - -	346
72	440-448	Arteries and Capillaries - - -	186
73	450-458	Veins and Lymphatics - - - - - -	324
74		Remainder - - - - - - - - - - - -	137

k

460-519 RESPIRATORY SYSTEM - 7.2 %

75	460-466	Acute Infections - - - - - - - -	118
76	480-486	Pneumonia - - - - - - - - - - - -	203
77	490-493	Bronchitis, Emphysema - - - - 493-Asthma (121)	196
78	500-508	Upper Respiratory Tract - - - 500-Tonsils and Adenoids (326) 504-Deflected Nasal Septum(115)	687
79	510-519	Other Diseases - - - - - - - -	334
		Remainder - - - - - - - - - - -	14

520-577 DIGESTIVE SYSTEM - 8.0 %

81	520-529	Oral Cavity and Jaw - - - - - -	115
82	530-537	Stomach, Duodenum - - - - - - -	281
83	540-543	Appendicitis - - - - - - - - - - -	115
84	550-553	Abdominal Hernia - - - - - - - -	391
85	560-569	Intestine, Peritoneum - - - -	390
86	570-577	Liver, Gallbladder - - - - - - - 571-Cirrhosis of liver (100) 574-Cholelithiasis (114)	443
		Remainder - - - - - - - - - - -	0

580-629 GENITOURINARY SYSTEM - 8.3 %

87	590-599	Urinary System - - - - - - - - -	532
88	600-607	Male Genital Organs - - - - - -	272
89	610-616	Breast, Ovary - - - - - - - - -	253
90	620-629	Uterus, Female Genitals - - - 626-Menstruation Disorder(350)	677
		Remainder - - - - - - - - - - -	61

630-678 CHILDBIRTH AND COMPLICATIONS - 7.9 %

92	630-634	Pregnancy Complications - - -	125
93	640-645	Abortion - - - - - - - - - - - - -	116
94	650-662	Delivery - - - - - - - - - - - - - 650-Without Complication(527) 657-Prolonged Labor (147) 658-Perineum Laceration (241)	1314
95		Remainder - - - - - - - - - - -	128

680-709 SKIN AND SUBCUTANEOUS TISSUE - 3.1 %

96	680-686	Infections - - - - - - - - - - - -	290
97	690-698	Other Inflammations - - - - - -	136
98	700-709	Other Diseases - - - - - - - - -	232
		Remainder - - - - - - - - - - -	0

710-738 MUSCULOSKELETAL SYSTEM - 5.0 %

99	710-718	Arthritis, Rheumatism - - - - 713-Osteoarthritis (102)	190
100	720-729	Osteomyelitis - - - - - - - - - 724-Internal Derangement (101) 725-Displaced Disk (142)	502

k			
101	730-738	Other Diseases - - - - - - - - - -	379
		Remainder - - - - - - - - - - - -	0
	740-759 CONGENITAL ANOMALIES - 2.0 %		
102		Remainder - - - - - - - - - - - -	426
	760-779 PERINATAL MORBIDITY CAUSE - 1.1 %		
103		Remainder - - - - - - - - - - - -	231
	780-796 ILL-DEFINED CONDITIONS - 4.5 %		
104	780-789	Symptoms - - - - - - - - - - - - - - 785-Abdomen (110)	715
105	790-796	Senility et al. - - - - - - - -	254
	800-999 ACCIDENTS - NATURE OF INJURY - 10.6 %		
106	800-809	Skull, Spine Fracture - - - -	248
107	810-819	Upper Limb Fracture - - - - - -	215
108	820-829	Lower Limb Fracture - - - - - -	244
109	830-839	Dislocation - - - - - - - - - - -	113
110	840-848	Sprains - - - - - - - - - - - - - -	141
111	850-854	Intracranial Injury - - - - - - 850-Concussion (105)	151
112	870-879	Head, Neck Laceration - - - -	127
113	880-887	Upper Limb Laceration - - - -	119
114	920-929	Contusion - - - - - - - - - - - -	102
115	960-979	Adverse Effect-Medicines - - -	150
116		Remainder - - - - - - - - - - - -	662
	Y00-Y30 SUPPLEMENTARY CLASSIFICATIONS - 8.0 %		
117	Y00-Y13	Exams Without Sickness - - - - Y03-Follow-up Exams (190) Y09-Sterilization (122)	644
118	Y20-Y29	Classification of Liveborn - - Y20-Single, not Immature (998)	1057

Explanation of contents: The hours listed for the outpatient clinics are those that were scheduled per week as listed in the clinic schedule published by the Chief of Outpatient Service on 1 April 1973. One category is defined for each clinic listed. The information accompanying the list of inpatient categories is discussed in the main text on page 120.

TABLE 13. PATIENT DISTRIBUTION

Area	Outpat.	Inpat.	Lim.Svc.	Total
	PERCENT OF HOSPITAL PATIENTS			
Allergy	2.79	.04	14.88	17.71
Cardiology	1.28	1.12		2.40
Chest	.45	.48	.15	1.08
Dermatology	2.32	.17	.01	2.50
Emergency Room	3.91		.10	4.01
Endocrinology	.18			.18
Gastroenterology	.18			.18
General Medicine	2.96	.07	.22	3.25
General Practice	13.08		.69	13.77
General Surgery	1.62	.05		1.67
Gynecology	3.00		.25	3.25
Hematology	.13			.13
Neurology	.49	.05		.54
Neurosurgery	.32	.02		.34
Obstetrics	2.33		.19	2.52
Occup. Therapy	.12			.12
Opthamology	5.00	.44	9.93	15.37
Orthopedics	3.99	.88		4.87
Otolaryngology	4.31	.65		4.96
Pediatrics	5.78		1.15	6.92
Physical Therapy	1.45			1.45
Plastic Surgery	.22	.01		.23
Proctology	.17			.17
Psychiatry	1.70	.65		2.35
Psychology	.17	.16	.44	.77
Thoracic Surgery	.34			.34
Urology	1.67	.09		1.76
Total	60.02	4.92	28.02	92.96

TABLE 14. PATIENT DISTRIBUTION BY AREA AND TYPE OF SERVICE

Area	% DISTRIBUTION IN AREA			% OF GROUPING BY:		
	Outpt	Inpt.	LmSvc	Outpt	Inpt.	LmSvc
Allergy	15.74	.23	84.03	4.64	.79	53.11
Cardiology	53.30	46.70		2.14	22.83	
Chest	41.97	44.12	13.91	.76	9.71	.54
Dermatology	92.65	6.86	.05	3.86	3.48	.04
Emergency Room	97.48		2.56	6.52		.36
Endocrinology	100			.31		
Gastroenterology	100			.30		
General Medicine	90.67	2.39	6.94	4.93	1.58	.81
General Practice	95.00		5.00	21.80		2.46
General Surgery	96.84	3.16		2.70	1.07	
Gynecology	92.10	.14	7.76	5.00	.09	.90
Hematology	100			.22		
Neurology	90.57	9.43		.82	1.05	
Neurosurgery	93.62	6.38		.54	.47	
Obstetrics	92.46		7.54	3.89		.68
Occup. Therapy	100			.21		
Opthamology	32.57	2.89	64.54	8.34	9.02	35.42
Orthopedics	81.91	18.09		6.65	17.92	
Otolaryngology	86.85	13.15		7.18	13.26	
Pediatrics	83.44		16.56	9.62		4.09
Physical Therapy	100			2.42		
Plastic Surgery	95.41	4.52		.38	.22	
Proctology	97.60	2.40		.28	.09	
Psychiatry	72.30	27.70		2.83	13.26	
Psychology	22.63	20.48	56.89	.29	3.23	1.59
Thoracic Surgery	100			.56		
Urology	94.59	5.41		2.78	1.94	
Total	-	-	-	100	100	100

TABLE 15. NUMERICAL PATIENT DISTRIBUTION

Area	Number of Patients			
	Outpat.	Inpat.	Lim.Svc.	Total
Allergy	13852	193	73929	87974
Cardiology	6367	5378		11945
Chest	2257	2373	748	5378
Dermatology	11498	851	61	12410
Emergency Room	19441	1	503	19945
Endocrinology	925			925
Gastroenterology	914			914
General Medicine	14691	387	1125	16203
General Practice	65021		3424	68445
General Surgery	8041	262		8303
Gynecology	14932	22	1259	16213
Hematology	667			667
Neurology	2458	256		2714
Neurosurgery	1601	109		1710
Obstetrics	11600		946	12546
Occup. Therapy	624			624
Opthamology	24874	2206	49297	76377
Orthopedics	19830	4380		24210
Otolaryngology	21399	3241		24640
Pediatrics	28703		5698	34401
Physical Therapy	7215			7215
Plastic Surgery	1124	54		1178
Proctology	855	21		876
Psychiatry	8441	3233		11674
Psychology	872	789	2192	3853
Thoracic Surgery	1684	2		1686
Urology	8284	474		8758
Total	298170	24432	139182	461784

TABLE 16. WORKLOAD OF ADJUNCT SERVICES

Category	Outpatients			Inpatients			Total
	Number	# per pat.	% of total	Number	# per pat.	% of total	Number
Lab Tests	1091496	3.66	57.0	821719	33.6	43.0	1913215
Pharmacy Units	344270	1.15	74.0	120380	4.93	26.0	463650
Pulmonary Studies	406	0.0014	58.7	285	0.0116	41.3	691
X-Ray Exposures	157217	0.527	65.1	84149	3.44	34.9	241366
Audiograms	4300	0.0144	92.8	334	0.0136	7.2	4664
Anesthesiology	841	0.0028	6.0	13074	0.533	94.0	13915
Dialysis				333	0.0136	100	333
Cobalt/Cesium Trtmt	1790	0.006	59.3	1227	0.0502	40.7	3017
EEG	713	0.0025	68.9	321	0.0132	31.1	1034
ECG	6699	0.0224	53.5	5822	0.238	46.5	12521
Fluoroscopic Exams	3057	0.0119	57.2	2287	0.0936	42.8	5344
Radioisotope Studies	6747	0.0226	69.5	2963	0.1212	30.5	9710
Radioisotope Therapy	9	-	37.5	15	-	62.5	24
Other Deep Therapy	76	-	96.2	3	-	3.8	79
Physical Therapy				12855			12855
Occupational Therapy				6133			6133

TABLE 17. DISTRIBUTION OF SURGICAL PATIENTS

GROUP	AREA OF SURGERY	NUMBER	% OF SURGERY	% OF INPATIENT
01-05	Neurosurgery	202	2.0	.86
06-14	Opthamology	355	3.5	1.52
16-21	Otolaryngology	887	8.9	3.80
22-23	Thyroid and Adrenals	35	.3	.15
24-30	Vascular and Cardiac	161	1.6	.69
32-35	Thoracic	133	1.3	.57
38-48	Abdominal	1047	10.5	4.98
50-52	Proctology	232	2.3	.98
54-61	Urology	451	4.5	1.93
65	Breast Surgery	84	.8	.36
67-72	Gynecology	1049	10.5	4.48
74-78	Obstetrics	2379	23.8	10.20
80-90	Orthopedics	1145	11.5	4.90
92-94	Plastic Surgery	534	5.3	2.28
95-98	Oral, Maxillofacial	103	1.0	.44
99	Dental	40	.4	.17
A1-A2	Biopsy	418	4.2	1.79
A4-A5	Diagnostic Endoscopy	516	5.2	2.25
A8-A9	Diagnostic Radiography	239	2.4	1.01
	Total	10010	100	42.86

TABLE 18. EXAMPLES OF INPATIENT LENGTH OF STAY DISTRIBUTION

			Military	Civilian	10-18	18-40	40-55	>55
CODE 301 COUNT=509 LOS=23.2 days								
	MALE	LOS	23.1	4.5	22.9	23.1	-	-
		COUNT	471	2	98	373	-	-
	FEMALE	LOS	43.4	15.7	35.8	26.5	-	-
		COUNT	14	22	4	28	-	-
CODE 303 COUNT=207 LOS=30.3 days								
	MALE	LOS	40.2	13.0	16.3	40.4	16.1	15.2
		COUNT	132	57	7	124	44	14
	FEMALE	LOS	-	13.0	-	-	13.4	-
		COUNT	-	18	-	-	11	-
CODE 401 COUNT=320 LOS=14.2 days								
	MALE	LOS	35.5	11.8	-	30.0	21.1	9.6
		COUNT	57	102	-	42	72	44
	FEMALE	LOS	-	8.2	-	8.5	7.4	9.0
		COUNT	-	161	-	35	61	61
CODE 500 COUNT=326 LOS=4.6 days								
	MALE	LOS	11.0	2.1	4.6	10.7	-	-
		COUNT	90	97	30	82	-	-
	FEMALE	LOS	-	2.1	2.0	2.9	-	-
		COUNT	-	133	42	38	-	-
CODE 626 COUNT=350 LOS=4.0 days								
	FEMALE	LOS	17.5	3.4	-	5.3	3.1	2.6
		COUNT	15	335		146	168	30
CODE 650 COUNT=527 LOS=3.6 days								
	FEMALE	LOS	-	3.6	3.8	3.6	-	-
		COUNT	-	526	43	479	-	-

TABLE 19. DISTRIBUTION OF PATIENTS BY PERSONAL STATUS

	OUTPATIENTS				INPATIENTS				TOTAL	
Category	Number	% of pat.	% of outpt	% of ctgy	Number	% of pat.	% of outpt	% of ctgy	Number	% of pat.
Active Duty	47793	14.8	16.03	78.8	12854	3.98	52.87	21.2	60647	18.78
Dependent	103900	32.2	34.85	97.5	2666	.85	10.89	2.5	106566	33.05
Retired	48024	14.9	16.10	91.2	4640	1.45	18.96	8.8	52664	16.35
Dependent	93956	29.1	31.51	96.0	4052	1.25	16.36	4.0	98008	30.35
Other	4497	1.4	1.51	95.2	220	.07	.88	4.8	4717	1.47
Totals	298170	92.4	-	-	24432	7.60	-	-	322602	-

APPENDIX A

EXPLANATION OF MATHEMATICAL AND STATISTICAL TERMS

This section is provided for hospital personnel who may be unfamiliar with mathematical and statistical concepts used in the explanation of the model. The explanations in this appendix are not intended to be authoritative. Suitable texts should be consulted by those wishing a more detailed and complete explanation.

A. EXPLANATION OF SELECTED ITEMS

1. Weighted Average

There are two basic methods to compute the average value of a parameter measuring a specified population characteristic. The first is to select a sample at random from the whole population of concern and compute the simple average:

$$\text{AVERAGE} = \frac{\text{Sum of observed values}}{\text{Number of samples}}$$

This method is appropriate for homogeneous populations or for ones in which no clear cut subdivisions are apparent.

The second method is used to obtain a more representative average when there are subdivisions of a population and those subdivisions are known or suspected to have different average values of the same parameter. A random sample is drawn and the simple average computed for each subdivision.

These averages are combined into the population average by adding together a percentage of each subdivision simple average. The percentage is computed as the proportion of total population represented by each subdivision population (not as the proportion of samples in each subdivision to the total number of samples). The following example illustrates the computation of both averages for comparison:

POPULATION = 25% DIVISION 1 + 75% DIVISION 2

Division 1 sample: 100,75,86

Division 2 sample: 3,6,4,8,5

$$\text{SIMPLE SAMPLE AVERAGE} = \frac{287}{8} = 35.87$$

$$\text{Division 1 sample average} = \frac{261}{3} = 87$$

$$\text{Division 2 sample average} = \frac{26}{3} = 5.2$$

$$\text{WEIGHTED SAMPLE AVERAGE} = 25\%\ (87) + 75\%\ (5.2) = 25.65$$

The importance of the difference in the two procedures is that, having taken a sample, the average values are used as estimates of the true population parameter. If the example represented dollars expended per person and one wished to estimate the cost of 100 people then a simple average would yield an estimate of $3587 which is $1022 more than the cost to be expected if the 100 people are a representative group of the whole population.

2. The Sigma Notation

The symbol 'Σ' is used to denote the addition of a group of variables. A series of examples should suffice to clarify its use in the main text.

a. $\sum_i a_i$, $i = 1\text{-}3$

This is equivalent to: $a_1 + a_2 + a_3$. The i under Σ indicates the subscript which will change to designate the different variables. A range for i is specified as shown above or by $\sum_{i=1}^{3}$.

b. $\sum_i a_{ij}$, $i = 1\text{-}3$

This is equivalent to: $a_{1j} + a_{2j} + a_{3j}$. The value of j is specified or there is a separate string of sums for each value of j, e.g.: $a_{11} + a_{21} + a_{31}$ and $a_{12} + a_{22} + a_{32}$.

c. $\sum_i \sum_j a_{ij}$, $i = 1,2$ $j = 1\text{-}3$

This is equivalent to: $(a_{11} + a_{12} + a_{13}) + (a_{21} + a_{22} + a_{23})$. With multiple subscripts, start at the outer and set the first value of the indicated subscript, in this case i, until the inner is reached. Then let the subscript indicated for the inner vary over its range. Repeat this procedure until all subscripts have been allowed to cover their respective ranges. For example:

$$\sum_i \sum_j \sum_k a_{ijk} = (a_{111} + a_{112}) + (a_{121} + a_{122}) + (a_{211} + a_{212}) + (a_{221} + a_{222})$$

Since addition is the only operation used with the sigma notation in the model, these examples should clarify any confusion arising from the use of this shorthand notation.

3. Linear Programming

A simple explanation of a linear programming model does not do justice to the power of the technique in analysis. The following explanation is provided only so that non-analyst personnel may appreciate the reasoning behind some of the model formulations.

A decision maker normally has a set of goals in mind for the organization which he manages. That organization requires resource inputs, labor and capital to produce output with which to meet the goals of management. There are limits to the supply of resources, labor and capital. A linear programming model attempts to quantify each of these facets of an organization into linear equations. One equation quantifies the goals of management, for example, to minimize cost, maximize profit or maximize output. Technology equations model the process of producing output. Constraint variables quantify the limits imposed on the organization.

A simple objective can be to maximize the quantity Y which represents some output. The quantity Y is generated by the linear equation: $a + b_1X_1 + b_2X_2$. The variables X_1 and X_2 represent the inputs and the coefficients b_i represent the amounts of each input necessary to produce one unit of Y. The cost of producing Y is: $\$_1X_1 + \$_2X_2$, which is

simply the sum of the cost per unit of input times the amount of input. Constraints may be of the form that requires cost to be less than some specific quantity and the maximum amount of each resource that can be used to be specified. The question is then how to maximize Y by adjusting the quantities of X_1 and X_2 which are used to produce Y.

While the concept is relatively simple, the equations can be built up in very complicated ways, with several interactions, so that it is very difficult to manually compute the optimum solution. The following set of sample equations serve to illustrate this. The simple equations can be complicated by: 1) increasing the number of inputs; 2) making the inputs X_i themselves linear functions of other quantities; and 3) defining more than one output variable, say Y_1 and Y_2 which are combined by a weighted average into the total output, Y. Example:

$$Y = aY_1 + (1-a)Y_2 \ , \ 0 \leq a \leq 1$$

$$Y_1 = b_0 + b_1X_1 + b_2X_2$$

$$Y_2 = c_0 + c_1X_3 + c_2X_4$$

$$X_1 = d_0 + d_1W_1$$

$$X_3 = e_0 + e_1Z_1 + e_2Z_2$$

APPENDIX B

ORGANIZATION OF OAKLAND NAVAL HOSPITAL

The detailed organization of Oakland Naval Hospital is provided in this appendix for general information. The charts on the following pages present the overall organization and the detailed breakdown of each component unit. The organization presented is that which existed prior to the creation of the Navy Regional Medical Center in January 1973.

Included with the organizational breakdown is data on the distribution of authorized personnel as listed in the Manpower Listing [Ref. 7]. Personnel in excess of authorization are not included. This data is recorded in the following format:

OFFICER/ENLISTED military - CIVILIAN

OVERALL ORGANIZATION STRUCTURE

Office of Commanding Officer

Director of Professional Services		Administrator
Services		Divisions
Anesthesiology	Opthamology	Data Processing
Dental	Orthopedic	Fiscal and Supply
Dermatology	Otolaryngology	Food Service
Laboratory	Outpatient	Operating Services
Medical	Pharmacy	Patient Affairs
Neuropsychiatric	Radiology	Military Personnel
Nursing	Preventive Medicine	Security
OB /´GYN	Surgical	Special Services
Clinical Investigation	Urology	
Pediatric	Neurosurgery	

OFFICE OF THE COMMANDING OFFICER (4/2-0)

Special Assistants (6/1-8)

Chaplain
Red Cross
Public Affairs Officer
Legal Officer
Safety Officer
Medical Librarian
Patient Care Coordinator

Boards and Commissions

Medical Records and Utilization
Tumor Board
Hospital Infection Board
Tissue Board
Pharmacy and Therapeutics
Graduate Training
Medical Library

Director of Professional Service

Administrative Office (0/0-3)
Photographic Laboratory (0/3-0)

Office of Administrator

Civilian Personnel (0/0-6)

ANESTHESIOLOGY SERVICE (14/0-2)

Administrative Branch
Anesthesia Branch
Inhalation Therapy Branch
Recovery Room Branch

DENTAL SERVICE (6/0-3)

Administrative Branch
Training Branch
Oral Diagnosis (0/2-0)
Prosthodontics (0/3-1)
Operative Branch (0/3-0)
Oral Surgery (0/6-0)
Periodontics (0/0-1)
Preventive Dentistry

DERMATOLOGY SERVICE (2/2-0)

LABORATORY SERVICE (14/0-2)

Lab Assistant School Branch
Clinical Pathology Branch (0/4-0)
- Blood Bank (0/4-7)
- Blood Collecting
- Hematology (0/7-1)
- Biochemistry
- Microbiology
- Urinalysis
- Drug Screening (0/0-13)

Pathologic Anatomy Branch (0/2-4)
- Histopathology Section
- Autopsy Pathology
- Pathology Records
- Surgical Pathology
- Cytology

MEDICAL SERVICE (14/0-2)

Allergy
Gastroenterology
Infectious Diseases
Oncology
Endocrine Metabolic
Cardiology (0/6-1)
Hematology
Nephrology
Pulmonary Disease

NEUROPSYCHIATRIC SERVICE (15/0-1)

Special Assistants
- Nursing Supervisor
- Administrative Assistant

Neurology Branch (0/2-0)
- Inpatient Section
- Outpatient Section
- EEG Technician School

Social Service Branch (0/0-4)
Training Branch
- Residency Section
- Neuropsychiatric Technician School
- Chaplain Training
- Research

Psychology Branch (0/42-1)
Psychiatry Branch (0/0-1)
- Inpatient Section
- Outpatient Section
  - Child Guidance

NEUROSURGERY SERVICE (2/0-1)

Diagnostic Branch
Therapeutics

NURSING SERVICE (146/161-1)

Hospital Corps Detail Branch
Clinical Nursing (0/29-113)
Nursing Specialities (0/5-11)
Education and Training

OB/GYN SERVICE (10/0-2)

Obstetrics Branch
  Inpatient Section
  Outpatient Section
Gynecology Branch
  Inpatient Section
  Outpatient Section

OPTHAMOLOGY SERVICE (13/6-2)

Opthamology Branch
Optometry Branch

ORTHOPEDIC SERVICE (12/0-1)

Clinic (0/6-1)
Physical Medicine (9/16-0)
Surgery Branch
Prosthetic Research Laboratory (1/0-14)

OTOLARYNGOLOGY SERVICE (11/9-0)

Otolaryngology Branch
Speech and Hearing Center (0/0-8)

OUTPATIENT SERVICE (4/13-0)

Administration (0/0-26)
Clinical (0/0-3)
Military Sickcall and Physical Exams

PEDIATRIC SERVICE (7/0-0)

Outpatient Branch (0/0-2)
Inpatient Branch

PHARMACY SERVICE (3/1-0)

Procurement and Storage Branch (0/0-1)
Dispensing Branch (0/10-0)
Manufacturing and Compounding (0/1-0)

PREVENTIVE MEDICINE UNIT (3/1-1)

Training Branch
Administration
Military Medicine Branch

RADIOLOGY SERVICE (8/0-0)

Diagnostic Branch (0/16-0)
Radiation Therapy (0/0-1)
Nuclear Medicine (0/2-0)
Radiation Safety
Administration and Training (0/0-5)

SURGICAL SERVICE (14/0-2)

Plastic Surgery (0/5-0)
Thoracic and Cardiovascular Branch
General Surgery (0/20-0)
Tumor Board Cancer Registry
Supervisor Branch (0/0-2)
  Central Supply
  Operating Room
  Special Care

UROLOGY SERVICE (6/6-1)

Clinical Branch
Surgery Branch
Training Branch

CLINICAL INVESTIGATION CENTER (2/12-1)

Research Branch (0/0-6)
Clinical Branch (0/0-1)
Administration (0/0-2)

INTERNS - 26

HOSPITALMAN SCHOOL

Instructors (0/12-0)
Students (0/107/0)

DATA PROCESSING DIVISION (1/0-0)

Data Systems (0/0-2)
Control (0/1-0)
Operations (0/0-7)

FISCAL AND SUPPLY DIVISION (1/0-1)

Fiscal Branch
- Budget and Accounting (0/0-7)
- Civilian Payroll (0/0-3)
- Collection Agent (0/1-2)
- Budget Reports and Statistics

Supply Branch (1/0-1)
- Control (0/0-5)
- Material (0/2-13)
- Purchase (0/0-8)
- Medical Repair (0/5-0)
- Equipment (0/0-1)

FOOD SERVICE DIVISION (1/0-0)

Administration and Stores (1/5-1)
Therapeutic Diet (2/0-1)
- Inpatient Section
- Education Section

Food Production and Service (0/0-94)
- Watch Sections (0/3-0)
- Meat Shop (0/0-1)
- Salad Room (0/0-1)

OPERATING SERVICES (1/1-1)

Housekeeping (0/0-49)
Linen Services (0/2-0)
- Distribution (0/0-4)
- Laundry (0/0-22)

General Service Branch (0/6-0)
- Office Services
- Information Services (0/2-0)
- Telephone Services (0/0-5)

PATIENT AFFAIRS DIVISION (2/0-1)

Medical Data (0/4-5)
Baggage Room
Medical Records (0/1-0)
- Transcribing (0/0-19)
- Reports and Files (0/0-5)

Registrar (0/4-0)
- Admissions (0/4-8)
- Disposition (0/0-4)
- Personnel Files (0/0-2)
- Decedent Affairs (0/0-1)

MILITARY PERSONNEL (2/1-1)

- Personnel Branch (0/3-5)
  - Officer Section
  - Enlisted Section
  - Reports and Statistics
  - Civil Affairs
- Education and Training (1/4-0)
  - Inservice Training Section
  - Educational Services
  - Training Aids
  - General Library (0/0-1)

PUBLIC WORKS (1/0-2)

- Housing and Administration (0/1-2)
- Transportation
- Maintenance Control (0/0-6)
- Maintenance and Utilities (0/0-2)
  - Machine Shop
  - Paint and Upholstery (0/0-7)
  - Carpenter Shop (0/0-6)
  - Air Conditioning and Refrigeration
  - Electric Shop (0/0-8)
  - Plumbing (0/0-9)
  - Heating (0/0-6)

SECURITY DIVISION (1/0-1)

- Administrative Branch (0/3-0)
  - Identification Cards
  - Vehicle Registration
  - Discipline
- Security Branch (0/6-0)
  - Security Section
  - Rehabilitation
  - Investigation
- Traffic Control
  - Master at Arms (0/8-0)
  - Quarters and Billeting
- Fire Department (0/0-8)

SPECIAL SERVICES DIVISION (1/4-1)

- Recreation Branch
  - Theater
  - Crew Library
  - Bowling
  - Swimming
  - Athletics
- Administrative Branch
- Property Branch

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A preliminary model for manpower and budget resource allocation in a Navy Regional Medical Center is formulated. Oakland Naval Hospital is used to illustrate the concept. A functional budget structure is proposed for management use in resource allocation decisions. Submodels of important supporting elements in the functional structure are developed. The problem of suitable definitions for patient category inputs

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is addressed. The model is suitable for use in analysis of many different types of health facilities with modification as discussed in the paper.

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